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# CHARACTERIZATION OF THE SUSPENDED-SEDIMENT REGIME AND BED-MATERIAL GRADATION OF THE MISSISSIPPI RIVER BASIN

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**Potamology Program (P-I)**

**Report 1**
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**Prepared by**

**Environmental Laboratory**
**U. S. Army Engineer Waterways Experiment Station**
**P. O. Box 631, Vicksburg, Miss. 39180**


**Prepared for**

**U. S. Army Engineer District, New Orleans**
**P. O. Box 60267, New Orleans, La. 70160**

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APPENDIX D: CHARACTERIZATION OF THE SUSPENDED-SEDIMENT REGIME AND BED-MATERIAL GRADATION OF THE OHIO RIVER BASIN

## PART I: ENVIRONMENTAL CHARACTERIZATION

### Introduction

1. The Ohio River Basin lies in the eastern portion of the United States, covering a total land area of 203,980 square miles with approximate dimensions of 400 by 550 miles.[1*] The basin is bounded on the north by drainages to the Great Lakes, on the east by the divide of the Appalachian Mountains, on the south by drainages to the Atlantic Ocean and the Gulf of Mexico, and on the west by tributary drainage areas of the Upper Mississippi River. The area represents about 6 percent of the total for the 48 contiguous states. The Ohio River Basin's geographic location and natural resources have been a major factor in the economic growth of the basin and the Nation, being strategically situated in the national market area as a source of raw materials, agricultural products, and manufactured goods.

2. The Ohio River is the greatest contributor of flow to the Lower Mississippi River. The stream originates at Pittsburgh, Pa., formed by the juncture of the Allegheny and Monongahela Rivers and then flows generally southwest for a distance of 981 miles to join the Mississippi River at Cairo, Ill. The floodplain is rather narrow, ranging from an average width of less than a mile in the Pittsburgh-Wheeling reach to slightly more than a mile in the Cincinnati-Louisville reach. Throughout most of the floodplain, about one-fourth mile of its width is normally occupied by the river. The limited valley lands, including much of the floodplain, are used intensively by industry. The Kanawha, Little Kanawha, Big Sandy, Licking, Kentucky, Salt, Green, Cumberland, and Tennessee Rivers flow into the Ohio from the south. These streams are generally deeply entrenched throughout their courses, with the rugged adjacent

* References are listed in the Reference section at the end of the text of this Appendix.

terrain limiting the location of communities and transportation routes in their watersheds. The Beaver, Muskingum, Hocking, Scioto, Little Miami, Great Miami, and Wabash Rivers flow through glaciated areas before discharging into the Ohio from the north. Their valleys are shallow, relatively broad, and suitable for agriculture.

3. The Ohio River Basin is composed of fifteen well defined subbasins: the Allegheny, the Big Sandy-Guyandotte, the Cumberland, the Great Miami, the Green, the Kanawha, the Kentucky-Licking, the Lower Ohio, the Middle Ohio, the Monongahela, the Muskingum, the Scioto, the Tennessee, the Upper Ohio, and the Wabash (Figure D1 and Table D1). A description of these subbasins is provided in the following paragraphs.

4. The Allegheny River drainage, together with that of the Monongahela River, comprises the headwaters of the Ohio River. The Allegheny Subbasin occupies 11,700 square miles, or six percent of the Ohio River Basin and contributes 60 percent of the Ohio River flow at Pittsburgh. This subbasin extends farther north and east then the other Ohio River tributary subbasins, being about 175 miles long on a north-south axis and 130 miles wide. Approximately 25 percent of the topography of the subbasin has been modified by the advance of the last continental ice sheets, which covered the northwest portion of the subbasin. The topography of the glaciated area is generally rolling plains with gentle slopes. Many lakes and swamps have been formed on the glacial deposits because the postglacial drainage has not had time to develop. Below and to the east of the glacial advance, the topography is characterized by moderate to strong relief. In the mountain upland and high plateau areas of the basin, the land is largely dissected by its drainage. The total length of the Allegheny River is 325 miles. The river valley is relatively narrow in its upper reaches, whereas in the middle portion it is from one-half to more than a mile wide. Near Pittsburgh, the valley is one-half mile wide and the navigation pool averages about 800 ft. The banks in most reaches are generally from a few feet to 8 ft above the normal water surface and are moderately to heavily wooded.

5. The Guyandotte-Big Sandy Subbasin is situated in the south-central portion of the Ohio River Basin, covering 5950 square miles or

nearly three percent of the Ohio River Basin. The Big Sandy and one of its tributaries, Tug Fork, form the entire length of the Kentucky-West Virginia Boundary. Subbasin topography is rolling to rugged, with the maze of hills and valleys covered mostly by forests and pastureland. Many of the valleys are extremely narrow with steep slopes rising abruptly from the streambeds. The steep hillsides generally leave little room for development in the river valleys except within the floodplains. The subbasin has a history of recurring heavy rainfall from winter storms and summer thunderstorms. Runoff in this subbasin has been greater than the average for the Ohio River Basin, causing frequent floods within the subbasin and contributing substantially to Ohio River flood problems. In contrast, extended droughts in the subbasin, although infrequent, have caused crop losses and acute water shortages.

6. The Cumberland River Subbasin, situated in the southern portion of the Ohio River Basin, has an area of 17,920 square miles, or nine percent of the land in the basin. This subbasin has an east-west alignment, for the most part parallel to the Ohio River. The upper portion of the subbasin lies in the Cumberland Mountains, where streams flow in deep narrow valleys and have gradients ranging from 10 to 12 ft per mile. The subbasin has a history of recurring, heavy, widespread rains and summer thunderstorms with intense rainfall. Runoff in this subbasin has been greater than the average for the Ohio River Basin, and flooding occurs frequently in some locations. Conversely, extended droughts, although infrequent, have caused severe crop losses and other problems associated with acute water shortages. The Cumberland River is formed by the confluence of Poor and Clover Forks in the Appalachian Plateau region. From that point the stream flows southwesterly into Tennessee and then turns and flows in a northwesterly direction back into Kentucky, joining the Ohio River 58 miles above the confluence of the Ohio and Mississippi Rivers at mile 920.6.

7. The Great Miami Subbasin is situated in the north-central portion of the Ohio River Basin, covering 5400 square miles or three percent of the Ohio River Basin. The topography in the upper and middle portion of the subbasin is typified by level to gently rolling plains broken by

the wide valleys of the larger streams. In the lower reaches of the subbasin, the terrain changes to rolling and hilly as the river nears the Ohio main stem. The subbasin has a history of heavy rains and summer thunderstorms with intense rainfall. Runoff in this subbasin is less than the average for the Ohio River Basin; nevertheless, flooding occurs in many areas. Extended droughts, although infrequent, have caused major crop losses and acute water shortages. The Great Miami River rises in Logan County, Ohio, and flows in a southwesterly direction for approximately 172 river miles to its confluence with the Ohio River near the Ohio-Indiana state line, 490.9 river miles downstream from Pittsburgh.

8. The Green River Subbasin, situated in the southwestern part of the Ohio River Basin, has a general east-west alignment, covering 9230 square miles or nearly five percent of the Ohio River Basin. The topography varies from rugged hilly terrain in the eastern part of the subbasin to deep valleys and cavern areas in the central section, and the swampy and wide floodplain area in the western or downstream section. The subbasin has a history of recurring heavy winter rains from widespread storms and also summer thunderstorms with intense rainfall. Runoff in this subbasin has been greater than the average for the Ohio Basin, and flooding occurs frequently. Nevertheless, infrequent extended droughts have caused major crop losses and acute water shortages. The headwaters of the Green River are in Lincoln and Casey Counties, Ky. The river flows 330 miles in a northwesterly direction to the Ohio River, where it discharges at mile 784.4.

9. The Kanawha Subbasin, situated in the southeastern section of the Ohio River Basin, lies mostly on the Appalachian Plateau. The topography is rolling to rugged with much of the land being heavily forested. The subbasin covers 12,200 square miles, which represents six percent of the area included in the Ohio River Basin. The subbasin has a history of recurring heavy snowfall, widespread heavy rains (occasionally from hurricane-influenced storms), and local intense rainfall during summer thunderstorms. Extended droughts, although rare, have caused crop losses and severe water supply shortages. Runoff in this subbasin has been greater than the Ohio River Basin average and contributes materially to

flooding in the Ohio River. Flood damages in the Kanawha Subbasin account for about seven percent of the damages within the Ohio River Basin. The Kanawha River is formed by the confluence of the New and Gauley Rivers in Fayette County, W. Va. From the point of origin it flows northwesterly for 95 miles to its junction with the Ohio River 265.6 river miles downstream from Pittsburgh. Below Kanawha Falls the Kanawha is 500 to 800 ft wide at normal stage. The floodplain is 12 to 50 ft above the normal water surface, with the banks having relatively steep slopes to the water's edge. The Gauley River width varies from 50 ft in the upstream reaches to 400 ft near its mouth. The streambanks range from 5 to 10 ft in height near the source to 30 ft near the mouth.

10. The Kentucky-Licking Subbasin is situated in the south-central portion of the Ohio River Basin, with 6790 square miles in the Kentucky drainage and 3950 in that of the Licking. These two drainages, together, account for five percent of the total area of the Ohio River Basin. The topography of the subbasin varies from the rolling Bluegrass Region to the rugged Appalachian Mountains. The subbasin has a history of heavy winter and spring rains and summer thunderstorms with intense rainfall. In contrast, extended droughts, although infrequent, have caused major crop losses and acute water supply shortages. Runoff is greater in this subbasin than the average for the Ohio River Basin. Floodwaters from the Kentucky and Licking Rivers contribute significantly to Ohio River flood problems. Located south of the glaciated portion of the Ohio River Basin, the subbasin's physical features are generally the result of geologic strata being exposed by erosion following a broad upwarping of the Paleozoic Era known as the Cincinnati Arch. The Kentucky River rises in southeastern Kentucky and flows 427 miles northwesterly to its confluence with the Ohio River at mile 545.7. The Licking also has its headwaters in southeastern Kentucky and flows northwesterly to its junction with the Ohio River opposite Cincinnati, Ohio, at mile 470.2.

11. The Lower Ohio River Subbasin includes all drainages to the Ohio main stem from mile 545.7 (the confluence of the Kentucky River with the Ohio) to mile 981.2 (the confluence of the Ohio and the Upper Mississippi Rivers), with the exception of the drainages of the Kentucky,

Green, Wabash, Cumberland, and Tennessee Rivers. The main stem falls some 121 ft in elevation through this subbasin as it winds through a valley bordered by an almost continuous band of rough, unglaciated land. The area of this subbasin covers 12,570 square miles or six percent of the Ohio River Basin. With the exception of those tributaries listed above and the Salt River, most of the tributaries to the Ohio through this reach are considered minor. The Salt rises in Boyle County, Ky., and flows due north about 40 miles before turning abruptly westward to flow another 75 miles to its junction with Rolling Fork, then north again for 12 miles where it enters the Ohio River near Louisville, at mile 630.0. The total drainage area of the Salt River is about 2,900 square miles.

12. The Middle Ohio River Subbasin includes all drainages to the Ohio main stem from mile 265.6 (the confluence of the Kanawha River with the Ohio) to mile 545.7 (the confluence of the Kentucky River with the Ohio), with the exception of the drainages of the Kanawha, Guyandotte, Big Sandy, Scioto, Licking, Great Miami, and Kentucky Rivers. The main stem falls some 117 ft in elevation as it passes through this subbasin, bordered by an almost continuous band of rough unglaciated land. The valley of the Ohio River in the vicinity of the mouth of the Kanawha contains extensive alluvial deposits, some being two and one-half miles wide and over 100 ft thick. The Middle Ohio River Subbasin has a history of recurring heavy rainfalls from winter storms and summer thunderstorms. Runoff in this subbasin has been greater than the average for the Ohio River Basin, causing frequent floods. With the exception of those tributaries listed above, most of the tributaries to the Ohio in this subbasin are considered minor excluding the Little Miami and Little Sandy Rivers. The Little Miami drains an area of 1760 square miles, or 20 percent of the subbasin. This stream rises in Clark County, Ohio, and flows in a general southwesterly direction for approximately 106 river miles to its confluence with the Ohio River in the eastern suburbs of Cincinnati at mile 463.4. The topography in the upper and middle portions of this drainage are typified by level to gently rolling plains broken by the wide valleys of the larger streams. In the lower reaches

of the Little Miami, the terrain changes to rolling and hilly as the stream nears the Ohio River. The Little Sandy River has its headwaters in Elliott County, Ky., and flows generally northeast 84 miles along a tortuous course to its confluence with the Ohio River at mile 336.4.

13. The Monongahela Subbasin is situated in the northeastern portion of the Ohio River Basin (adjacent to the Allegheny Subbasin), covering 7380 square miles or nearly four percent of the Ohio River Basin. The Monongahela River is formed by the confluence of the West Fork and Tygart Rivers in Marion County, W. Va. The river flows in a northerly direction for 129 miles and joins the Allegheny River at Pittsburgh to form the Ohio River. The subbasin has a history of recurring heavy winter snowfall and summer thunderstorms with intense rainfall. Runoff in this subbasin is greater than that of the Ohio River Basin average. The Monongahela contributes about 40 percent of the Ohio River annual flow at Pittsburgh and five percent of the flow at Cairo, Ill. During peak runoff periods, high flows in the Monongahela contribute materially to Pittsburgh and Ohio River flood problems. In contrast, extended droughts, although infrequent, have caused major crop losses and acute water shortages. The prevalence of rugged terrain severely restricts the acreage suitable for cultivation. Except in localized areas, erosion is not now severe, but considerable erosion has occurred in the past due to lumbering, poor soil management practices, and mining activities. Erosion is currently greatest in the western third of the subbasin due to unprotected strip-mined areas, highly erosive shale soils, cultivated or overgrazed slopes, and unprotected soil in urban developments, particularly in the Pittsburgh area. The remainder of the Monongahela drainage is either forested or under a protective grass cover.

14. The Muskingum River Subbasin, situated in the north-central portion of the Ohio River Basin, is the largest drainage area in the state of Ohio. The subbasin contains 8040 square miles, or four percent of the Ohio River Basin. The topography near the Ohio River is rolling to rugged with much of the land being heavily forested; the remainder of the subbasin is relatively flat. The Muskingum is formed by the junction of its two principal tributaries, the Tuscarawas and

Walhonding Rivers in Coshocton County, Ohio. The Muskingum then flows south for 110 miles where it enters the Ohio River at mile 172.1. This subbasin has a history of recurring heavy winter and spring rains and summer thunderstorms with intense rainfall. Although runoff in this subbasin has been less than the average for the Ohio Basin, flooding occurs frequently, yet extended droughts, although infrequent, have caused major crop losses and severe water shortages.

15. The Scioto River Subbasin, situated in the north-central portion of the Ohio River Basin, covers 6510 square miles or three percent of the basin. The subbasin lies entirely within the state of Ohio. This drainage has a history of recurring heavy rains and summer thunderstorms with intense rainfall, often causing floods. Infrequent extended droughts, however, have caused substantial crop losses and acute water supply shortages. Runoff in this subbasin has been less than that of the Ohio River Basin average. The Scioto rises in northwestern Ohio, flows east 60 miles where it is joined by the Little Scioto, then south 175 miles where it enters the Ohio River at mile 356.5. The upper reaches of the Scioto consist of a flat, poorly drained, glaciated plateau with marsh lands and badly developed channels that are inadequate for high flows. Between Prospect and Columbus, the river is confined between steep banks with practically no floodplain. South of Columbus the stream is flanked by level plains of rich farm land up to three and one-half miles wide in some places.

16. The Tennessee River is the major tributary of the Ohio River and drains the southernmost portion of its watershed. This tributary empties into the Ohio 47 miles upstream from the junction of the Ohio with the Mississippi River.[2] The drainage area of the Tennessee River Subbasin is 40,910 square miles, or almost exactly one-fifth that of the Ohio River Basin. The Tennessee has its headwaters in the mountains of western North Carolina, western Virginia, eastern Tennessee, and northern Georgia. Two of its seven major tributaries, the French Broad and Holston Rivers, join just east of Knoxville, Tenn., to form the Tennessee. From Knoxville to the mouth (647 miles) the river is channelized for navigation through a series of nine multipurpose reservoirs.

The flow between Knoxville and Chattanooga is augmented by the contributions of three major tributaries: the Little Tennessee, Clinch, and Hiwassee Rivers. The Tennessee River then crosses northern Alabama where it is joined by the Elk River. After forming the Alabama-Mississippi boundary for a few miles, the river makes its second passage across Tennessee where it receives the Duck River, and then crosses the western tip of Kentucky to its mouth at Paducah.

17. The Upper Ohio Subbasin includes all drainages to the Ohio main stem from mile zero (the confluence of the Monongahela and Allegheny Rivers) to mile 265.6 (the confluence of the Kanawha River with the Ohio), with the exception of the drainage of the Muskingum River. The main stem falls 172 ft in elevation through this reach as it passes through an almost continuous band of rough unglaciated land. Excluding the Hocking, Little Kanawha, and Beaver Rivers, most of the tributaries to the Ohio entering this subbasin are considered minor. The Hocking River rises in Fairfield County, Ohio, and converges with the Ohio main stem at mile 199.4. The Hocking drainage includes an area of 1200 square miles or nine percent of the Upper Ohio Subbasin, and except for its glaciated headwaters area, the drainage is hilly with moderately steep slopes. The Little Kanawha River watershed covers an area of 2309 square miles lying entirely within the state of West Virginia, and represents 17 percent of the total area of the Upper Ohio River Subbasin. The Little Kanawha River heads in southwestern Upshur County and flows 165 miles to the northwest to its mouth at mile 184.7 on the Ohio River. From the headwaters to a point 44 miles downstream, the river has a fall of approximately 29.5 ft per mile. The rate of fall for the remaining 121 miles is only about 1.5 ft per mile. The Little Kanawha watershed has a history of recurring heavy snowfall, widespread heavy rains (occasionally from hurricane-influenced storms), and local intense rainfall during summer thunderstorms. Prolonged droughts have caused crop losses and extreme water supply shortages. Runoff in this watershed has been greater than the Ohio Basin average. The topography of the watershed is rugged throughout with elevations in the headwaters reaching approximately 2200 ft. Soil erosion has been moderate to severe over much of

the area, particularly where the slopes have been deprived of adequate vegetative cover as a result of lumbering, farming, and mining activities. The Beaver River drainage, situated in northeastern Ohio and northwestern Pennsylvania, covers 3130 square miles, or 23 percent of the Upper Ohio River Subbasin. The Beaver is formed by the confluence of the Mahoning and Shenango Rivers in Lawrence County, Pa., and flows in a southerly direction for 21 miles, where it enters the Ohio River at mile 25.6. The topography is rolling to flat with much of the land in crops and pasture. The climatic history of the Beaver River drainage is characterized by winter snowfall greater than the Ohio River Basin average and frequent summer thunderstorms with intense rainfall; however, the runoff is less than the average for the basin. But as in other subbasins, extended droughts have caused major crop losses and acute water shortages, although not frequently.

18. The Wabash River Subbasin, situated in the extreme northwestern portion of the Ohio River Basin, covers 33,100 square miles, or 16 percent of the Ohio River Basin. From its headwaters in Mercer County, Ohio, the stream flows in a northwesterly direction into Indiana, across the upper third of that state, then it turns south to form the border between Indiana and Illinois. The Wabash enters the Ohio River at mile 848.0. Exclusive of the southeastern portion, which is hilly and rolling, the subbasin drainage area is, in general, a glaciated region of moderate relief, where the streams have gentle slopes and broad flat valleys. The natural drainage regime in the northern part of this subbasin is very poorly defined.

## Physiography and Geology

19. Two distinguishable major physical divisions are present in the Ohio River Basin: the Appalachian Highlands Division, which occupies 48 percent of the basin, and the Interior Plains Division, which covers 52 percent.[3] The major divisions are further divided into provinces as follows:

| Major Division | Province |
|---|---|
| Appalachian Highlands | Appalachian Plateaus |
| | Blue Ridge |
| | Valley and Ridge |
| Interior Plains | Central Lowland |
| | Coastal Plain |
| | Interior Low Pleateaus |

Most of the basin lies within the Appalachian Plateaus, the Interior Low Plateaus, and the Central Lowland provinces (Figure D2).

20. The Appalachian Plateaus Province covers the eastern portion of the Ohio River Basin in a shallow structural trough composed primarily of Pennsylvania sandstone formations interbedded with siltstone, limestone, shale, and numerous coal seams.[1] The province includes the unglaciated areas of Ohio, Pennsylvania, and New York and extends from the eastern basin boundary westward to central Ohio and eastern Kentucky. The rugged topography is a result of the differences in resistance of the rocks to weathering and runoff. The permeable sand and gravel deposits in the valleys of the drainage system provide moderate groundwater supplies. Extensive forest cover, poor quality soils, narrow valleys, steep stream gradients, flash floods during the rainy season, and low streamflows during dry seasons are characteristic of this area.

21. The Interior Low Plateaus Province, lying at somewhat lower elevations and to the southwest of the Appalachian Plateaus Province, covers most of the area south of the Ohio River and the unglaciated areas of Illinois and Indiana. Much of the plateau is underlain by units ranging in age from Ordovician through Mississippian; however, coal-bearing rocks of Pennsylvanian age are present in the western coalfield region of Kentucky. Doming and erosion of the limestone surface rock, which covers most of the region, has resulted in the rolling terrain forming the Lexington Plains and Bluegrass regions, where farming predominates. The areas of rugged local relief are well forested.

22. The Central Lowland Province glacial deposits north of the Ohio River are underlain with Paleozoic bedrock similar to that of the

Interior Low Plateaus Province. The glaciers covered most of this province at least twice during the Pleistocene Epoch, leaving deposits of drift that now form some of the richest agricultural lands in the basin. The terrain is flat to rolling, with the depth of drift varying with the elevations of the underlying rock and alluvial surfaces. In central Ohio, much of the area has deposits from 40 to 200 ft in depth. The advance and recession of glaciers caused extensive changes to drainage system patterns north of the present course of the Ohio River. Buried preglacial and interglacial river channels now provide substantial groundwater resources and have flow patterns that differ greatly from today's surface streamflow patterns.

23. The Blue Ridge and the Valley and Ridge Provinces cover a small portion of the southeastern part of the Ohio River Basin. The Coastal Plain Province parallels a segment of land along the left bank of the Tennessee River in western Tennessee and Kentucky, and a narrow strip adjacent to both banks of the Ohio River below its confluence with the Tennessee. The Blue Ridge Province contains most of the principal headwater streams of the Tennessee River Subbasin. This province is characterized by high, rugged mountain topography. Cliffs occur only in the recently formed river gorges of quartzites and slates. Other principal rocks present are granites, schists, gneisses, and marbles. The Valley and Ridge Province forms an area extending from Virginia into Georgia and Alabama, and is characterized by narrow parallel ridges, some of them uninterrupted for nearly 100 miles, with slightly broader intervening valleys. The rocks are principally sedimentary and consist mainly of limestones, dolomites, and calcareous shales. The soil types are closely related to the underlying rock, such that the best agricultural land is in the limestone valleys, while the cherty soils on the ridges are better suited for forest use. The Coastal Plain Province is an area of low relief with a maximum difference in elevation of about 300 ft. The broad, flat valleys are filled with thick deposits of alluvium. Exposed clastic rocks are unconsolidated and deeply underlain by Paleozoic rocks. Much of the area is poorly drained and best adapted to forests.

24. In a broad sense, the Ohio River Basin geology can be characterized as a region of slightly disturbed Paleozoic sedimentary rocks that range in age from Cambrian to Permian. On the basis of general lithology and economic importance, they are subject to two general divisions: (a) the coal measures, and (b) a great series of calcareous sediments that extend from the base of the coal measures down through the Cambrian. The coal measures form the broad Appalachian plateaus of the eastern third of the basin in Pennsylvania, West Virginia, eastern Ohio, eastern Kentucky, and eastern Tennessee. They also underlie the central lowlands of western Indiana, western Kentucky, and eastern Illinois. These measures consist of a great series of sandstones and shales containing many important coal beds. The calcareous rocks underlie a broad belt extending through the central portion of the basin in middle Tennessee and Kentucky, western Ohio, and eastern Indiana. Dominating other rocks in this area are the limestones and calcareous shales. The northern and western portions of the basin, including nearly all of the right-bank drainage area of the Ohio River below Portsmouth, Ohio, have been glaciated. In this area, bedrock is generally buried beneath thick deposits of glacial drift.

## Soils

25. Three basic soil types are present in the Ohio River Basin: the gray-brown podzolic soils found over most of the eastern half of the basin as well as in some sections of the western part of the basin; the red and yellow podzolic soils found in the Cumberland and Tennessee subbasins; and the prairie and reddish-prairie soils found along the lower Ohio main stem and in the lower portion of the Wabash Subbasin. More specific descriptions and locations of soil types present in the basin are provided in Figure D3 (based on National Cooperative Soil Survey Classification of 1967 compiled by USDA, Soil Conservation Service). A general narrative description of the soil types is provided below.

26. The gray-brown podzolic soils are derived from organic matter, mostly deciduous trees; this soil type has become incorporated with the

mineral soil, yielding a mull layer several inches thick. Lower layers of the soil show some accumulation of silicate clays, often possessing a blocky structure that does not always facilitate drainage. Although this type of soil is not considered to be highly fertile, the climate in which it occurs is favorable for agricultural activity. The red-yellow podzolic soils originated under a mild climate, abundant rainfall, and mixed forests, often deciduous, in combination with parent materials ranging from granites to limestones and marine sediments. Regions covered by the prairie and reddish-prairie soils are generally covered by native and planted grasses, which have generated a deep, rich, granular, dark brown to reddish top soil that is highly suitable for agricultural activities.

## Climatology

27. The Ohio River Basin lies entirely within the humid eastern United States, where weather systems generally move from west to east.[1] This area is also occasionally influenced by masses of cold polar air from the Arctic and warm tropical air from the Gulf of Mexico. Either system may move in at any time of the year with the accompanying effects of chilling or warming.

28. Precipitation in the Ohio River Basin, including snowfall, varies considerably with location and from year to year. Total annual precipitation ranges from 32 in. along the northeastern boundary of the basin to localized areas of 80 or even 90 in. in the mountainous region of northern Georgia and nearby parts of western North Carolina (Figure D4). Average snowfall varies from 8 in. at Nashville, Tenn., to 95 in. at Jamestown, N. Y. General snows in the southern portion of the basin are infrequent, and many winters pass without a snowfall that stays on the ground more than a few hours. Spring and summer thunderstorms with intense rains of short duration are common. The mean annual precipitation for the basin is 46 in.

29. Summer temperatures vary throughout the basin and are influenced in part by differences in elevation. The average July temperature

ranges from 66°F to 80°F; however, summer temperatures have exceeded 100°F, and several days of temperatures of over 90°F can be expected each year throughout the basin. Winters range from moderately cold in the southwest to severe in the extreme northeast. January is the coldest month, when temperatures average from 26°F to 43°F. Several days of subzero readings can be expected each winter in the northeastern part of the basin. The warm, humid summers create ideal conditions for one or more agricultural harvests. The average frost-free season varies from 120 days in the northeast to 220 days in the southern part of the basin.

30. Storm occurrences vary, with extreme floods seldom present over the entire basin during the same period. Major flood-producing storms occur most frequently from December to April. Droughts are usually spotty or local in nature, and crops are seldom a total loss; however, loss of income due to lower yields is common. The drought effects on production are usually more pronounced between 1 July and 15 August. Widespread droughts occur on the average of once every six to seven years.

31. Prevailing winds with velocities averaging 6 to 12 miles an hour are generally from a south or southwesterly direction in the flatlands, but usually originate from a more westerly direction in the mountains. Decadent hurricanes produce major damage in the Appalachian Mountain areas during the spring-summer seasons. An average of six tornadoes per year strike Indiana, Kentucky, Ohio, and Tennessee.

## Hydrology

32. The streams in the Ohio River Basin, except for those in the glaciated areas, are essentially remnants of a pattern formed on a peneplain, which slopes to the north and west.[1] The present incised pattern in many areas still exhibits the general meandering of these former mature streams, although slopes are steeper and valleys are narrower. The Monongahela, Allegheny, and upper Ohio Rivers were originally part of the St. Lawrence River drainage flowing to Lake Erie. With the exception of the upper Allegheny, these rivers flowed north

through the Beaver and Grand River valleys. The Big Sandy River was probably the original outlet for the upper Kanawha, which then flowed through the preglacial "Teays" Valley, up the present Scioto River across Indiana and Illinois, and into the Mississippi River. The Ohio from near present mile 409 to Cairo is essentially in its original location with the exception of some changes caused by glaciation. Several periods of glaciation cut off the drainage to the north, hence the Ohio River became the main outlet to the south. Each glaciation produced changes in the stream patterns, and the flow of many streams in Illinois, Indiana, Ohio, and Pennsylvania were reversed, adding to the Ohio River's discharge.

33. Streams in the Ohio River Basin vary from steep mountain courses with cascades and rapids to sluggish, meandering waterways. The streambed gradients of the major tributaries vary from more than 100 ft per mile in the headwaters to less than two-tenths of a foot in the flat areas near the Ohio main stem. In general, the streambeds are steepest in the headwaters, except in areas of glacial deposition where remnants of marshes and bogs result in relatively flat and sluggish upstream areas; thus, the intermediate reaches are the steepest in these areas.

Runoff

34. The mean annual runoff from the Allegheny and Monongahela Subbasins is more than 23 in., representing 60 percent of the average Ohio River Basin precipitation; whereas, in the Wabash drainage the runoff is 12.8 in. or about 31 percent (Figure D5). In general, runoff is greatest in the eastern and southern parts of the basin and lowest in the northwestern glaciated areas. The volume of streamflow is greatest from January through April, because half of the annual flow normally occurs in this four-month period.

Groundwater

35. Moderate to plentiful groundwater supplies are available throughout most of the glaciated areas and alluvial valleys of the basin. The unconsolidated deposits to the north of the Ohio River contain large groundwater storage reservoirs in buried flow channels formed by preglacial drainage systems. The permeable sands and gravel deposits in the

valleys of the drainage system, although somewhat limited in areal extent, are sources of high yield. Some of these could be made even more productive by artificial recharge during high streamflow periods.

36. Bedrock formations underlying the basin vary greatly in their hydrologic characteristics. Mississippian sandstone aquifers in the northwestern part of the Allegheny Subbasin are capable of high yields. Ordovician and Mississippian limestones in Kentucky and West Virginia are sources of numerous springs and well supplies. Although these sources are widespread, they are only capable of serving moderate needs. Areas with bedrock formations of shale and siltstones, such as those flanking both sides of the Ohio River between Wheeling and Point Pleasant, W. Va., yield little water. There are also areas of poor supply where bedrock is near the surface in the glaciated regions of Indiana and Ohio and in the nonglaciated parts of Kentucky, where the Ordovician formations of the Cincinnati Arch protrude through the surface.

Flooding

37. There is a long history of flood problems in the Ohio River Basin. Starting with an Indian trader's description of a flood in the early 1750's, recorded accounts indicate that there have been one or more floods on the main stem or its tributaries during virtually every decade since 1750. As early as 1808 levees for partial protection of agricultural lands were built by private owners in the Wabash River Subbasin. The three greatest floods of modern record occurred in 1913, 1936, and 1937. The 1913 flood caused such major disruption to the economy of the Great Miami River Subbasin in Ohio that the residents of that subbasin undertook, at their own expense, major works to control floods at Dayton and in downstream communities. Since the series of great floods and indications by the Congress in 1936 of a Federal interest in the control of flooding, many flood control projects have been constructed with Federal funds to cope with problems in localized areas and to cope with the widespread flood problems throughout the basin.

38. The flood season on the Ohio main stem lasts from December to April with major floods usually occurring from January through March.

Floods on the tributaries may occur during any month. Many of the major floods on the Ohio have had discharges above flood stage continuing for many days. The flood of March 1964 exceeded flood stage at Cincinnati for 11 days. By comparison, also at Cincinnati, the 1937 inundation exceeded flood stage for 19 days and the flood in 1963 for 21 days. Flooding caused by ice jams is more of a problem on the tributaries than on the main stem. Ice jams usually occur at locations where constrictions or other stream characteristics cause ice flows to pile up.

### Water supply

39. Water uses in the Ohio River Basin include withdrawals for municipal, industrial, electric power generation and cooling, mining, agriculture, and recreation. Current water supply requirements are generally satisfied throughout the basin, being readily obtainable from streamflow, groundwater, or surface storage. Current projections for the basin indicate that the major water withdrawals are expected to increase over 200 percent by 2020 and comsumption will increase by about 250 percent (Table D2). The greatest withdrawals will be for electric power cooling, increasing from 19.2 billion gallons per day (BGD) in 1965 to 63.0 BGD by 2020.

## Vegetation

40. The Ohio River Basin was almost entirely forested prior to clearing by pioneers. According to Küchler,[4] the natural vegetation in the basin was distributed areally (Figure D6) as follows:

| Map Unit | Vegetation Type | Percentage of Area Covered |
|---|---|---|
| G | Central and eastern grassland | 0.1 |
| H | Central and eastern grassland and forest combinations | 5.6 |
| I | Eastern needleleaf forest | 0.2 |
| J | Eastern broadleaf forest | 88.0 |
| K | Eastern broadleaf and needleleaf forest | 6.1 |

The most current land-use inventories available (1967) indicate that approximately 29 percent of the basin area is used for cropland, 16 percent for pastures and range, 40 percent in forest, with the remainder being used for urban areas, lakes, airports, etc. (paragraphs 89-92).

## PART II: CULTURAL HISTORY

41. Settlement in the Ohio River Basin and the resulting changes in land use have had an effect on the erosive processes, and in turn, the sediment regime. In the following paragraphs, a brief history of exploration and settlement, the development of economic and social trends, and an examination of land-use changes are presented. Emphasis is given to those cultural activities that have had impacts on the sediment regime.

### Exploration and Settlement

42. The first humans to reach the Ohio River Basin were the descendants of the early migrants who crossed the Bering Strait from Asia. These primitive people were followed into the basin by the Norsemen and Welshmen from Europe. The greatest influx of settlers came following the French and Indian Wars and after the United States obtained jurisdiction over the basin.

#### Indians[5,6]

43. By 5000 B.C. members of the Indian Knoll Culture were probably in the Ohio River Basin. The main concern of these early dwellers was survival. They lived in caves or rock shelters to protect themselves from the elements and ate mollusks that they collected from basin streams. With the exception of bits of charred bones embedded in layers of broken shells and earth, little else remains of this primitive group. Archeologic findings show that there was little or no weapon and tool development during this era.

44. Following the Indian Knoll Culture, another group, generally referred to as mound builders, began to dominate basin life (100 B.C.). The accomplishments of these people are best preserved by the spectacular mounds that they constructed. The last of the mounds builders, known as the Middle Mississippi Culture, vanished around 1700 A.D., their demise being blamed primarily on the Europeans. Many of the Middle Mississippians were driven from the basin and eventually absorbed

into the nomadic tribes of the southwest, while others were killed or sold into slavery in the Spanish West Indies.

Early Europeans[5,6]

45. According to legend, Welshmen visited the Tennessee River before the time of Columbus. The Cherokees tell that these people landed near present-day Mobile, Ala., and were driven inland by hostile Indians to the Tennessee. Ancient fortifications constructed along the Hiwassee River, in present-day eastern Tennessee, are generally attributed to the Welsh. Norsemen are thought to have reached the valley of the Ohio River about the same time as the Welsh, but even less is known about them. Some authorities suggest that the winged helmet and crested ceremonial staff of the Hopewell Culture could have been the result of an encounter that these Indians had with the Norsemen.

Spanish explorers[5-7]

46. Hernando De Soto's expedition of 1540 marks the beginning of written history in the basin. Accompanying De Soto were 600 or more Europeans, Indian carriers, a large number of horses, and a herd of hogs. He landed at Tampa Bay in late May 1539 and probably moved up the Flint and Savannah Rivers and entered the basin in the western part of North Carolina. The expedition visited the Hiwassee River, the Tennessee River near Chattanooga, and the headwaters of the Little Tennessee River. De Soto and his followers traveled the interior of the North American continent for approximately four years, but their expedition did not find the gold or splendor that existed in the empires of the Aztecs and Incas.

French explorers[5,7,8]

47. By 1650 France had a firm footing in North America with colonies in New France (Québec) and Acadia. At this time, England had already established several Atlantic coast settlements, and the Dutch were in New Amsterdam (New York). All three nations had heard Indian rumors of a southwest-flowing river that eventually reached the sea. They assumed this sea to be the Pacific Ocean. Control of such a stream would boost the status of any European power. In 1669, at the command of King Louis XIV of France, Robert Cavelier, Sieur de La Salle, and 20

Frenchmen in company with a group of Seneca Indians began an expedition to the Ohio River. Some historians believed that La Salle crossed Lake Erie and made portage to a tributary of the Ohio River and then travelled downstream on the Ohio beyond the Falls of the Ohio (near present-day Louisville, Ky.) where he spent the winter of 1669-1670.

48. In 1671 France formally claimed the Ohio River Basin. Shortly afterward the lower reaches of the Ohio began to appear on French maps with a fair degree of accuracy. For years to come the upper reaches of the basin streams would remain uncharted. Louis Joliet and Père Jacques Marquette passed by the mouth of the Ohio on their 1673 trip down the Mississippi River and again on the return trip upriver. La Salle, without a doubt, also passed by the mouth of the Ohio River in 1682 on his voyage down the Mississippi River to claim all lands drained by the latter stream in the name of France. By the end of the seventeenth century France had begun to construct a line of trading posts, which later became military posts, from the Great Lakes to the Gulf of Mexico, including Post Vincennes on the Wabash River and Post Ouiatenon near the Wabash-Tippecanoe confluence (present site of Lafayette, Ind.). There were, however, no other posts in the basin.

English explorers and traders[5,6]

49. Between 1654 and 1664 an English fur trader, Abraham Wood, is said to have visited tributaries of the Ohio River during his trapping seasons, but unfortunately none of his travels were documented. Wood did, however, send an expedition led by James Needham to investigate the back country west of the Virginia mountains in 1673. Needham was killed by one of the Indian guides, but Gabriel Arthur, who accompanied Needham, was captured and adopted by the Cherokees. He later escaped to tell the story of his adventures to his sponsor, Abraham Wood, who in turn reported this information to authorities in Carolina.

50. Thomas Nairne and Price Hughes realized that if England's Carolina Colony was to develop trade via the Tennessee River they must develop the friendship of the Cherokee to thwart a possible French-Cherokee alliance. Unfortunately Nairne was captured by hostile Indians and burned at the stake in 1715 prior to establishing any trading

posts. Hughes shared Nairne's ideas for development of the frontier; however, he envisioned actual settlements rather than trading posts. Hughes submitted his plan for colonization to London, and established alliances with the Chickasaws and Choctaws, but he, too, was attacked and killed by Indians before he could see his dream realized. In addition to Nairne and Hughes there were a number of the so-called "Carolina traders," who exercised great diplomacy with the Indians in securing trade for their goods in the 1700's. These men learned a great deal about the "back country" of the Ohio River Basin and the tribes that occupied it.

Colonization of the basin[5,6,8,9]

51. A Scottish baronet, Sir Alexander Cumming, arrived in Charles Town (Charleston) around 1730 and became involved in a number of promotional enterprises that promised a great future for the Carolinas (divided into North and South Carolina in 1710) and for the lands west of the mountains. Cumming succeeded in charming the colonists, the Indians, and even the Royal Court in London with his various developmental schemes. Many persons, no doubt, believed him and mortgaged their property to raise investment capital. He obtained a large amount of money and later returned to England with seven representatives of the Cherokee tribe, while absconding with 1500 pounds sterling of Carolina currency (the bulk of the capital of his investors). The Indians signed a perpetual treaty with the English stating that they were subjects of the crown and brothers of the English; thus, it was the removal of the last impediment to English settlement west of the Virginia Mountains.

52. In 1744 delegates from the English colonies of Virginia, Maryland, Pennsylvania, and New York met in Lancaster, Pa., with the Iroquois. These discussions resulted in the sale by the Iroquois to the English of a loosely defined tract of land west of these colonies. This agreement would later serve as a basis for English claims to the upper reaches of the Ohio River and its tributaries. On 18 March 1749 the English crown chartered the Ohio Company of Virginia. The major reason for the organization of this company was to anticipate the French by taking

possession of that territory southward of the Great Lakes. France decided that she must act immediately to counter any English attempt to settle these territories. In 1749 the Marquis de La Galissonnière, governor of New France, sent an expedition led by Pierre Joseph Céloron de Bienville to "plant the Arms of France upon the Ohio." He nailed the Arms of France to trees at a number of places along the Ohio, proclaiming the French ownership of the basin complete with prayers and a salute of firearms. He also buried plates bearing inscriptions that made a formal French claim to all land west of the Alleghenies.

53. King George II of England made an initial grant of 200,000 acres to the Ohio Company of Virginia. This grant was located in present-day West Virginia, on the left bank of the Ohio River between the Monongahela and Kanawha Rivers. The grant stipulated that if this first settlement were successful, the company would receive an additional 300,000 acres downstream. To open the territory, the Ohio Company asked Thomas Cresap to construct a road from Cumberland, Md. (on the Potomac River), to the Monongahela River and to build warehouses at each end. GEN Edward Braddock's forces completed the road begun by Cresap, which became known as Braddock's Road.

54. The Ohio Company employed Christopher Gist, a surveyor, to explore the upper Ohio as far downstream as the Falls of the Ohio and to locate suitable sites for settlement. Governor Robert Dinwiddie of Virginia instructed Gist to invite any tribes he would meet to a treaty meeting that would be held in 1752 at Logstown, an Indian town and trading post. Word of Gist's travels reached New France, and the French responded by assembling stores at Presque Isle (present site of Erie, Pa.) and building fortifications along the Allegheny. The French also formulated plans to build a fort at the confluence of the Monongahela and Allegheny Rivers, thus setting the stage for a future conflict. The Logstown meeting that Gist had widely publicized was held from 9-13 Jun 1752. At this meeting, representatives of the Shawnees, Delawares, and Miamis ratified the questionable grants made by the Iroquois at Lancaster, Pa., in 1744 in exchange for English goods of mediocre quality.

55. England's long-range plan was to extend her authority to the

Mississippi; however, the last remaining obstacle was the French presence. After Céloron made his formal claim, French forces or their Indian allies intercepted most of the English traders who came into the basin and seized their goods. The French had military posts established over much of the basin, including posts on the Wabash and in the Illinois Country in addition to posts along the shores of the Great Lakes. The stage was now set for the French and Indian Wars, which would decide whether the upper portion of the Ohio Basin would be part of the English Empire, and thus be open for trade and settlement from the colonies, or belong to France. Even more important was the question as to which nation, with its own language, form of government, and social structure, would dominate the future character of the basin. The Treaty of Paris (1763) ended not only this conflict but also a worldwide struggle. As a result, France had to concede all her possessions in North America. England received all the lands of the French and Spanish east of the Mississippi River (including the drainage basin of the Ohio River, New France, and Florida), with the exception of the "Isle" of New Orleans, and Spain received French lands west of that river plus New Orleans.

56. After the culmination of the French and Indian Wars, the English government, in an effort to appease basin Indians, ordered by the Proclamation of 1763 that the crest of the Appalachian Mountains be the western edge of the settlement frontier. This meant that settlement was now barred from the basin--the very reason that the conflict with the French had started. This proclamation did little to win endearment for the mother country in colonial America because it voided the western land claims of the colonies, even those whose original charters contained provisions for "sea-to-sea" grants.

57. In 1768 the English negotiated separate treaties with the Iroquois and the Cherokees to obtain title to some of the basin lands. These titles were regarded as somewhat questionable because not all of the major basin tribes were included in the negotiations. One such area was a large strip of land called Vandalia, which extended west of the mountains into the upper Ohio Valley--covering most of what is now West Virginia and eastern Kentucky. Settlement was facilitated by

Braddock's Road and by Forbes Road built by GEN John Forbes through southern Pennsylvania to Fort Pitt. By the beginning of the American Revolution, Pittsburgh and Wheeling had become thriving villages as a result of the influx of these settlers.

58. Along the southern frontier a number of pioneers were also moving westward. In 1769 a group of Virginians migrated into the Watauga Valley, located in present-day eastern Tennessee. These pioneers established an unauthorized government, the Watauga Association, which lasted until 1778 when Watauga became part of the revolutionary state of North Carolina.

59. After skirmishes with the Indians that resulted in a victory for Virginia troops at the mouth of the Kanawha River, Virginia gained title from the Shawnees in 1774 to those lands both south and east of the Ohio River. There had already been a great interest shown in these lands. As early as 1769 a frontier hunter, Daniel Boone of North Carolina, who wanted to encourage settlement of the bluegrass region of central Kentucky, enlisted the aid of 30 other men to clear the "Wilderness Road" from the Holston River through Cumberland Gap to the Kentucky River, where they established Boonesborough in April 1775.

60. During the American Revolution, George Rogers Clark obtained approval from Governor Patrick Henry to organize an expedition against the British, who had encouraged Indian raids on the frontier settlements of New York and Pennsylvania. In 1779 Clark assembled a frontier militia, marched down the Ohio as far as its confluence with the Cumberland, and then overland to Post Vincennes and the Illinois Country. With the help of the French residents (who welcomed Clark's presence), he secured control of these posts and subsequently diminished the danger of British and Indian attacks on basin settlements.

<u>American control of the basin</u>[5,6,9]

61. Representatives of the 13 colonies signed the Declaration of Independence on 4 Jul 1776, founding the United States of America. After the Revolution and recuperation from the strains of war, the various land companies again went about the business of basin development. The Ohio Company of Associates and the Scioto Company of Associates were both

given charters by Congress to settle lands north of the Ohio River. Congress established the "Territory North-West of the River Ohio," and by the Ordinance of 1787 provided for a government in this region. In the spring of 1788 the Ohio Company of Associates laid out the town of Marietta, and soon churches, schools, and defense blockhouses were also erected. During the same year, John Cleves Symmes purchased a million acres between the Great and Little Miami Rivers, and shortly thereafter Cincinnati and other villages were founded.

62. By 1819 all of one state (Kentucky) and parts of twelve others had been carved out of the lands comprising the Ohio River Basin (including West Virginia, which was part of Virginia prior to the Civil War) as follows:

| State | Date of Ratification of the Constitution or of Admission to the Union | Order of Ratification of the Constitution or of Admission to the Union |
|---|---|---|
| Pennsylvania* | 12 Dec 1787 | 2nd |
| Georgia* | 2 Jan 1788 | 4th |
| Maryland* | 28 Apr 1788 | 7th |
| Virginia* | 26 Jun 1788 | 10th |
| New York* | 26 Jul 1788 | 11th |
| North Carolina* | 21 Nov 1789 | 12th |
| Kentucky | 1 Jun 1792 | 15th |
| Tennessee | 1 Jun 1796 | 16th |
| Ohio | 1 Mar 1803 | 17th |
| Indiana | 11 Dec 1816 | 19th |
| Mississippi | 10 Dec 1817 | 20th |
| Illinois | 3 Dec 1818 | 21st |
| Alabama | 14 Dec 1819 | 22nd |
| West Virginia | 20 Jun 1863 | 35th |

* One of the 13 original colonies.

63. During the flatboat era (1800–1820), the Ohio River and its tributaries served as avenues of commerce, with most of the goods being bound for New Orleans. The boatmen sold their cargoes and boats in that city and often returned home via the Natchez Trace, a former Indian trail that ran 450 miles from Natchez to Nashville. Beginning around 1815, after the Napoleonic Wars in Europe, many Europeans migrated over the

mountains and floated down the Ohio or its tributaries bound for Natchez, New Orleans, or the Illinois Country. By 1819, twenty steamboats were operating between New Orleans and such interior cities as Louisville and Nashville; this number had increased to 100 by 1824. At the end of 1835 some 684 steamboats had been built and were operating in the Mississippi River Basin, including 304 constructed in Pittsburgh.

64. The Ohio River was a line of demarcation between the North and South during the Civil War. Kentucky and Virginia were torn by much turmoil regarding loyalties. Representatives from a number of western counties in Virginia who would not agree to the secession enacted by the Richmond legislature held two conventions in Wheeling; the first repudiated the act of secession, and the second created the new state of Kanawha, subsequently changed to West Virginia. West Virginia was admitted as the 35th state in 1863. The Civil War made demands on agriculture and industry. Basin residents began to exploit its mineral wealth, especially the vast coal reserves. New industry began to develop, such that basin cities were less dependent on the eastern states for the manufactured goods. By the end of the war the basin was almost completely settled, with the exception of the steepest mountainous areas that were not suited for agriculture, mining, or industry.

## Economic and Social Trends

65. After the French and Indian Wars, settlers began to claim the choicest parcels of Ohio River bottomlands. Early cultural growth was primarily agricultural, and industry and commerce developed as a result of farming. Transportation networks and metropolitan centers evolved later. Brief narratives are provided below on the development and growth of agriculture, commerce and industry, transportation, and population and urbanization in the Ohio River Basin.

### Agriculture[1,10]

66. The early agricultural history of the basin dates to the Indians, who probably were growing corn, tobacco, cotton, tomatoes, and potatoes around 900 A.D. Prior to 1700, the Indians of the Middle

Mississippi Culture excelled in agriculture and grew a variety of crops on the outskirts of their villages in much the same manner as the inhabitants of feudal Europe. The agricultural potential of the basin was recognized by early emigrants from the eastern seaboard colonies; however, the major obstacle to further development was the threat of Indian attack. In addition, land clearing and the removal of stumps were necessary over much of the basin to make the soil productive. Potential settlers welcomed news of such regions as the bluegrass country where land clearing was not necessary prior to cultivation.

67. Early efforts to manage water and protect farms can be traced back to 1808 when landowners along the Wabash River built levees to protect their farms from floods. In later years there was more levee construction and watershed development by various government agencies, especially the Corps of Engineers (CE) and the Tennessee Valley Authority (TVA). The TVA was responsible for the large-scale development of the Tennessee River watershed. This activity resulted not only in improved navigation on the Tennessee River, but also in flood protection and electrification for the farm by means of hydroelectric power generation.

68. Until the 1930's soil conservation practices were nonexistent in the Ohio River Basin, and much valuable topsoil was lost each year to water erosion. The USDA Soil Conservation Service (SCS) and state and local agencies were formed to develop plans to minimize the erosion and to instruct landowners and tenant farmers on better methods of farming that would conserve the soil. These measures and the flood control and electrification activities of the CE and TVA resulted in renewed prosperity for the farmer.

Commerce and industry[1,5,6]

69. The earliest industrial development in the basin was in response to agriculture. The first activity was probably the operation of mills by the French at their Wabash River posts in the early eighteenth century. Gradually more sophisticated industries evolved as towns grew and the basin inhabitants became less dependent on the east for manufactured goods.

70. Glassmaking was one of the earliest industries to be developed

in North America. By the 1820's Pittsburgh had a significant glass industry, which used the abundant locally available glass sand. The discovery of natural gas gave the glass industry additional impetus and brought about significant growth for the Pittsburgh-Wheeling area by the 1850's.

71. When Europeans arrived in the basin, petroleum (called "rock oil") seeped from the ground in many places. A number of the early explorers and travelers saw these seeps and made note of them in their journals. George Washington recorded in the diary he kept while traveling through the basin that he saw a "bituminous spring." The presence of oil was regarded as a nuisance to the drillers of the early nineteenth century who were trying to find salt water. Settlers had heard of the medicinal properties of petroleum from the Indians, and many enterprising individuals tried to find additional uses for the viscous liquid. On 28 Aug 1859, COL Edwin Drake and his associates found a large reservoir of oil at a depth of 69-1/2 ft near Titusville, Pa., on Oil Creek, a tributary of the Allegheny River. This discovery was the beginning of the American oil industry and a boom for the basin.

72. The production of iron in the English colonies dates back to the mid-1600's. At the beginning of the American Revolution, iron was mined and forged around the headwaters of the Monongahela River mainly by plantation owners, and as a result, many basin communities have "Forge" as part of their name. Soon the area around Pittsburgh and other cities downstream became important centers of iron production.

73. The industrial employment pattern of the basin bears a marked resemblance to that of the United States, particularly when the comparison is made at a level of industry aggregation (i.e., for major industry groups such as manufacturing, agriculture, mining, trade, etc.). In the basin, as in the Nation, manufacturing accounted for a growing share of the total employment between 1930 and 1960. More than one million jobs in manufacturing will be added in the basin between 1960 and 2010. Within this sector, the most significant absolute increases in employment are projected to occur in wood products and furniture, apparel, fabricated metal products, and electrical and nonelectrical machinery.

74. Until the Civil War the mining of large quantities of coal was not feasible due to the presence of the vast forests and the lack of mining equipment; however, by 1870, seventeen million tons were mined in the basin. It is in the mining sector where the most important differences between national and regional employment are found. The basin, which produces about three-quarters of the country's coal, had about 3 percent of its working population engaged in mining in 1960, while the national share was only 1 percent. The employment share of mining, unlike manufacturing, has undergone a drastic decline, especially since 1950; in the Nation as a whole that share declined by almost 40 percent, while in the basin it declined by more than 55 percent during the 1950-1960 decade.

75. A similar decrease in share has been experienced by agricultural employment. In 1930, this sector accounted for more than 20 percent of the total employment in the basin, whereas in 1960 it accounted for less than 7 percent. The historic decrease in the contribution of agriculture and mining to total employment in the Ohio River Basin is attributable in part to the growing proportion of jobs in the trades and services. Employment in the services is expected to grow at a threefold rate. By the end of the twentieth century, more persons can be expected to work in the services than in all the manufacturing industries combined.

76. Economic growth in the basin will continue, although at a somewhat lesser rate than that anticipated for the Nation as a whole. Based on available projective indices, the economic activities in the years 1980 and 2020 will be about 200 and 700 percent, respectively, of the 1960 levels.

Transportation[5,6,8-14]

77. Travel in the Ohio River Basin during the early days of habitation was by a combination of waterways and portages. The Indians later developed extensive trade with their distant neighbors on the North American continent and in the process blazed a number of trails. French explorers and trappers leaving Canada via the Great Lakes soon found that by carrying their canoes over relatively short portages, they

could reach basin streams and eventually the Ohio and Mississippi Rivers. The first pioneers used the Ohio River and its tributaries as avenues for commercial development. Historians have noted that in the mid-1700's whole cargoes of pork, flour, bacon, tallow, hides, and leather were annually transported in barges from the basin to other areas. In addition, these early water routes served to establish the development pattern of the basin, with major communities springing up along the main stem of the Ohio and its principal tributaries.

78. Floods and low flows along the Ohio hampered the movement of the earliest travelers. The Falls of the Ohio River, a shelf of limestone stretching diagonally across the Ohio and forming a natural dam between the "upper" and "lower" river, in the vicinity of what is now Louisville, turned back many expeditions. Measures to conquer this barrier to navigation were initiated in 1817 and eventually led to construction of the Louisville-Portland Canal on the Kentucky side, which was opened in 1830-1831.

79. Keelboats and flatboats dominated waterborne commerce on the Ohio River during the early nineteeth century. After construction of the New Orleans at Pittsburgh in 1811, the steamboat began to replace the keelboat and flatboat, becoming the principal mode of transportation on the Ohio for the remainder of the nineteenth century and the beginning of the the twentieth. The largest sternwheeler constructed was the Sprague, which was completed in 1901 for the Monongahela Consolidated Coal and Coke Co. of Pittsburgh. The Sprague pushed 60 barges with a cargo of 67,307 tons of coal down the Ohio and Mississippi Rivers in February 1907, a record still unsurpassed.

80. On 14 Apr 1820 Congress appropriated $5000 for a survey of the Ohio and Mississippi Rivers from the Falls of the Ohio to the Head of Passes. The long-range objective of this task was to develop a plan to improve navigation on these two streams. The results of the survey compared the Ohio to the Loire River of France and recommended that low dikes be constructed to contract the stream and deepen the channel. Congress then passed the General Survey Act of 1824, which provided for surveying and planning a national system of roads and improved waterways.

In the same act Congress gave the CE jurisdiction over navigation on inland waterways. Congress appropriated $75,000 in May 1824 for an experiment on the Ohio River to scour a channel across a sandbar by use of wing dams. Construction on the first wing dam was begun later the same year at Henderson Bar, downstream from Henderson, Ky., representing the first river training structure placed on the Ohio River.

81. In early 1825 the Chief of Engineers contracted with John Bruce to clear snags from the Ohio River from Pittsburgh to the mouth, and from the Mississippi River from the mouth of the Missouri to New Orleans for $60,000. MAJ Samuel Babcock was appointed project inspector by the Chief of Engineers. By mid-1825 Bruce claimed he had cleared the river from Pittsburgh to Wheeling. Although Babcock seemed pleased with the work, the rivermen and boat owners did not share his view because the trees Bruce had cut during low water were hazards to navigation during high flows. After an investigation, the contract was terminated and Babcock was put under arrest for his lax inspection efforts.

82. In 1875 a survey of the Ohio was made for the purpose of designing a 6-ft navigation channel using a series of locks and dams to provide the required lift. Channelization was completed in 1929 (9-ft project depth). Modernization of the system began in the late 1930's; currently modern high-lift dams are in place except in the lower reaches. The Ohio River waterways system now provides excellent access for the basin via the Mississippi River waterways system to the Gulf of Mexico, the Gulf Intracoastal Waterway, and the Great Lakes. Ohio River traffic once consisted mostly of downstream-bound coal and steel products; however, present upstream and downstream tonnages are about equal. Many types of commodities are now transported, including significant volumes of petroleum and petroleum products, chemicals, bauxite, and portland cement, plus sand, gravel, coal, and steel. Freight and passenger traffic for the Ohio River Basin in 1977 are given in Table D3. Except for periods of extreme flood flow or hazardous ice conditions, towboats operate throughout the year on the Ohio and its tributaries, pushing tows that may be more than 1100 ft long and hauling cargoes of 20,000 tons or more. The current Ohio River modernization plan provides for 19 dam-lock

units to replace the original system of 46 dams.

83. Barges of coal, grain, sand, and gravel, as well as other commodities move through the Tennessee River and its tributaries. Traffic on the Monongahela River consists primarily of coal transported from the mines of northern West Virginia and southwestern Pennsylvania to Pittsburgh area industries. The Kanawha River carries coal from West Virginia mines and chemicals to and from the chemical industry at Charleston. The Kentucky River Waterway moves a minor amount of freight traffic in its lower reach, with pleasure craft predominating in the upper reaches. The Green and Barren Rivers Waterway provides access to markets for coal from western Kentucky mines. The Cumberland River traffic consists mostly of petroleum products and building stone for Nashville markets. A new major waterway, the Tennessee-Tombigbee, is now under construction through Alabama and Mississippi. When completed in 1986, this waterway will connect the Tennessee River directly with the Gulf of Mexico.

84. In addition to the navigable waterways, the basin is now served by an excellent system of highways, railroads, pipelines, and airlines. In Cincinnati, for example, there are 7 rail lines, 101 trucking companies, airport facilities serving 7 major airlines, and 2 major bus lines. Pittsburgh has 7 scheduled airlines, 19 rail lines, 400 trucking companies, and a number of bus lines. This transportation system is necessary to handle one-fifth of the Nation's steel production. Additional important transportation terminals are located at Indianapolis, Louisville, Nashville, Knoxville, Huntington-Ashland, Evansville, and Chattanooga.

Population and urbanization[1,5-9,15]

85. Prior to the initial passage of European explorers through the basin, the Ohio River drainage was occupied by the Indians in a number of settlements. The population of these early Indian inhabitants is difficult to estimate; however, there were probably several thousand Indians in the basin when the Europeans arrived. Prior to the French and Indian Wars, the population of the basin was small as compared with the eastern seaboard. The first Federal census, taken in 1790, showed the population of the new Nation to be approximately 4 million; of this

number less than 5 percent were living west of the Appalachians. There were only three populated areas in the basin besides the eastern Tennessee settlements:

a. A 12,000-square-mile region in present-day Kentucky, having a population density of 18 persons per square mile.

b. An area of 1200 square miles adjacent to both banks of the Cumberland River in central Tennessee, having a population density less than 6 persons per square mile.

c. An 800-square-mile area along the banks of the Ohio and Kanawha Rivers in present-day West Virginia, having an even lower density than the Cumberland settlements.

86. In 1810 the combined population of Kentucky, Ohio, Indiana, and Illinois was 674,073; by 1830 the population had increased to 2,131,196.[5] These figures also include some inhabitants living in parts of the Upper and Lower Mississippi River Basins and in the Great Lakes Basin.

87. The 1910 Census (which also includes 1900 data) was taken by political units rather than by drainage basins. When a political boundary map is overlaid on a drainage basin map of the same scale, it is possible to make a fairly accurate estimate of the 1900 and 1910 populations for towns and cities in the basin having populations of 2500 or greater,* as follows:

| Year | Basin Population |
|---|---|
| 1900 | 13,823,000 |
| 1910 | 15,697,000 |

Adjusted statistical data from Reference 1 give the following population and projected populations for the basin:

| Year | Population or Projected Population |
|---|---|
| 1960 | 22,661,000 |
| 1980 | 27,625,000 |
| 2010 | 37,676,000 |

* Although the thirteenth decennial census of the United States taken in 1910 covered both urban and rural areas, the only available data were for cities and towns of 2500 or greater.

Cities were established and grew when settlers moved westward. Table D4 shows, in chronological order, selected basin cities and their dates settled.

88. In 1975, there were all or part of 36 Standard Metropolitan Statistical Areas (SMSA's) in the basin as follows:

| State(s) | SMSA |
|---|---|
| Alabama | Gadsden<br>Huntsville |
| Illinois | Champaign-Urbana-Rantoul |
| Indiana | Anderson<br>Fort Wayne<br>Indianapolis<br>Lafayette-West Lafayette<br>Muncie<br>Terre Haute |
| Indiana-Kentucky | Evansville |
| Kentucky | Lexington<br>Owensboro |
| Kentucky-Indiana | Louisville |
| Ohio | Akron<br>Canton<br>Columbus<br>Dayton<br>Hamilton-Middletown<br>Lima<br>Springfield<br>Youngstown-Warren |
| Ohio-Kentucky-Indiana | Cincinnati |
| Ohio-West Virginia | Steubenville-Weirton |
| North Carolina | Asheville |
| Pennsylvania | Erie<br>Johnstown<br>Pittsburgh |

| State(s) | SMSA |
|---|---|
| Tennessee | Knoxville<br>Nashville-Davidson |
| Tennessee-Georgia | Chattanooga |
| Tennessee-Kentucky | Clarksville-Hopkinsville |
| Tennessee-Virginia | Kingsport-Bristol |
| West Virginia | Charleston |
| West Virginia-Kentucky-Ohio | Huntington-Ashland |
| West Virginia-Ohio | Parkersburg-Marietta-Wheeling |

These SMSA's rank from among the largest to the smallest in the United States, and the large number of these areas reflects the high degree of urbanization in the basin. The prognosis for growth of the medium to smaller SMSA's is good; larger areas will probably experience a slight decline in population or rank.

## Land-Use Development

89. Land use and land-use change with respect to time play significant roles in defining the characteristics of a basin's sediment regime and bed-material gradation. Quantitative land-use information (i.e., maps or statistical data) is difficult to obtain on a basin-wide basis especially for different time frames. Many Federal, state, regional, and local agencies are engaged in the process of mapping land use, but the variations in methods used to obtain these data, their reliability, and even the choice of parameters used to quantify land use are widely diversified.

90. In all 14 of the states drained by the Ohio River and its tributaries, land-use mapping is in progress. The following land-use products have been published:

a. Alabama. The U. S. Geological Survey (USGS) in cooperation with the Alabama Development Office has prepared land use and land cover maps[16] as a part of the Land Use and Data Analysis (LUDA) program for the state keyed to the USGS topographic maps. A Report[17] defining categories used in the maps[16] was published in 1976. The SCS published a "Conservation Needs Inventory" (CNI)[18] in 1970. An additional effort of the SCS was the "Tennessee Valley Resource Conservation and Development Project,"[19] which contains land use for that portion of Alabama in the Tennessee River drainage.

b. Georgia. The SCS published a CNI[20] in 1970 containing land-use data by counties. As a part of the LUDA program, the USGS in cooperation with the Georgia Department of Natural Resources has produced land use and land cover maps[21] keyed to the USGS topographic maps. A report[17] defining the categories used in the maps[21] is available.

c. Illinois. A CNI[22] published in 1970 was made under the direction of a state committee representing agencies and organizations with conservation responsibilities and interests. The Illinois Cooperative Crop Reporting Service issues an annual summary[23] of agricultural statistics that contains some land use data.

d. Indiana. In 1968 the SCS compiled a CNI[24] presenting a comprehensive view of Indiana's land-use and conservation treatment needs. All 18 Planning and Development Regions in Indiana are currently involved in land-use mapping; however, there is a great variation in map scales and the number and type of classes used. The State Planning Services Agency is in the process of producing uniform county land-use maps.

e. Kentucky. Some Landsat mapping is being undertaken by various agencies, but mapping is not statewide. A CNI[25] was published by the SCS in 1970.

f. Maryland. A part of Garrett County is the only area in Maryland drained by the Ohio River. Land-use maps by counties[26] were prepared in 1973. The SCS published a CNI[27] in 1971.

g. Mississippi. Land-use photomaps[28] for all of Mississippi have been compiled from the NASA Earth Observation Aircraft Program. A CNI[29] published by the SCS is an additional source of land-use data.

h. New York. The SCS has prepared an "Erosion and Sediment Inventory"[30] that contains some land-use data by counties; in addition the SCS has compiled a CNI[31] for New York. Another useful land-use publication is the "Regional Land-Use Plan"[32] containing data for the three

counties in New York drained by the Ohio River. The Land Use and Natural Resource (LUNR) Inventory, administered by the New York State Office of Planning Services, has produced a wide range of material, including aerial photographs and transparent overlays based on USGS 7.5-minute quadrangles. Computer programs have also been developed under contract with Cornell University for the storage and retrieval of land-use information. Information regarding the LUNR project is available from the New York Office of Planning Services, Albany.

i. North Carolina. An individual land development plan[33] has been prepared for each county in North Carolina. The SCS published a CNI[34] in 1971.

j. Ohio. The Ohio Department of Natural Resources has prepared two reports on land use in the state using Landsat data.[35,36] The SCS published a CNI[37] in 1971.

k. Pennsylvania. The only statewide land-use publication for Pennsylvania is the CNI[38] prepared by the SCS. The state of Pennsylvania is in the process of mapping the entire state through the USGS LUDA Program. The Office of State Planning and Development for Pennsylvania has completed a land policy report[39] that identifies statewide land-use issues and problems and presents policies and specific recommendations for action.

l. Tennessee. The SCS published a CNI[40] in 1971. The TVA has done some land-use mapping in the Tennessee River drainage using color infrared photographs taken by NASA. Information concerning these land-use products can be obtained from the TVA, Chattanooga, Tenn.

m. Virginia. Although regional commissions are involved in land-use planning, the only statewide data are in the CNI[41] prepared by the SCS.

n. West Virginia. Land-use maps[42] covering the state have been prepared through the USGS LUDA program. A CNI[43] was published in 1970. In addition, the CE, Huntington District, has prepared a land-use study[44] for areas along a section of the Ohio River.

91. Land-use data for the 14 states have been mapped by political units rather than by watershed boundaries. The CNI's provide land-use data by county for 1958 and 1967. Data for years prior to 1958 are available by county from Federal decennial and agricultural censuses. Both the CNI's and the census data must be adjusted such that they are compatible with the watershed boundaries rather than the established political boundaries. The exceptions to this are the data for 1967 that

are stored on magnetic tape at the Iowa State University Statistical Laboratory, Ames, Iowa, that can be retrieved by either basin unit or political entity.

92. The following categories taken from CNI's have been used to quantify land-use change in the Ohio River Basin:

- a. Cropland. Irrigated and nonirrigated land that has been tilled within the last five years, including land planted in hay crops or used for orchards and vineyards.
- b. Pasture and rangeland. Pasture is defined as land planted in introduced grasses primarily for livestock consumption. Rangeland includes all natural grazing lands and lands seeded with a mixture of native climate-adapted grasses for grazing use; cropland abandoned for five years where the intended use is grazing; and wild hay, native hay, or rangeland meadow.
- c. Forest. Commercial and noncommercial woodlands and windbreaks of one acre or more; U. S. Forest Service and other Federal lands containing 10 percent (crown coverage) or more trees capable of producing timber or wood products or of exerting an influence on the water regime, and grazing woodlands.
- d. Other land. Farmsteads, roads, feedlots, ditch banks, fence and hedge rows, rural nonfarm residence, and other rural lands not suited for agriculture (e.g., marshes); Federally owned land not leased for grazing or for forestry; cities, towns, and built-up areas more than 10 acres; institutional and administrative sites; ponds, lakes, reservoirs, and other water bodies more than two acres in size; and any other areas that do not meet the requirements of a, b, or c.

Land-use data for the Ohio River Basin for four selected years are provided in Table D5 by the four categories defined above; the appropriate documentation of source material for each year is given below:

| Year | Reference(s) |
| --- | --- |
| 1860* | 45 |
| 1910 | 15 |
| 1935 | 46 |
| 1967 | 18,20,22,24, 25,27,29,31, 34,36,37,38 40,41 |

* Data for 1860 were collected for only three categories: cropland, pasture and range, and forest and other land (see Table D5).

## PART III: CHARACTERIZATION OF SUSPENDED-SEDIMENT REGIME

93. The amount of sediment discharge at any location within a river system is a function of many variables that fall into two general categories: the characteristics of the drainage basin and stream morphology, and the cultural impacts through the reach in question. The important drainage basin characteristics include geology and physiology (paragraphs 19-24), soils (paragraphs 25-26), climate (paragraphs 27-31), hydrology (paragraphs 32-39), and vegetation (paragraph 40).

94. The dominant sediment source in the Ohio River Basin is sheet erosion, which is characterized as a more or less uniform wearing away of the surface.[1] Lesser sources include gully and embankment erosion and valley trenching. Sediment yields generally are a minimum in the northeastern part of the basin and increase toward the southwest (Figure D7). The lower estimated annual sediment yields are found in the Allegheny, Upper Kanawha, Monongahela, and Muskingum River Subbasins (Table D6) and the greater yields in the Big Sandy and Guyandotte, Great Miami, Green, Kentucky and Licking, Lower Ohio, and Tennessee Subbasins.

### Cultural Influences on Suspended-Sediment Regime

95. In addition to the steep slopes found in this basin and the widespread use of the land for agricultural purposes, channel improvements, reservoirs, mining activities, and dredging (paragraphs 111-112) have had significant impacts on the suspended-sediment regime of the Ohio River Basin. These topics are further discussed below.

#### Channel improvements

96. Commercial transportation on streams in the Ohio River Basin has progressed from the canoes and flat-bottomed boats of the early 1800's to today's diesel-powered tows.[2] As the Nation expanded, the need for transporting raw materials and manufactured goods necessitated the development of waterways suitable for navigation. This need resulted in the construction of a network of canals by state governments and private enterprises in Pennsylvania, Kentucky, Ohio, Indiana, and

Illinois early in the 19th century. Federal participation in the development of navigation channels in the Ohio River Basin began in 1824, following an act of Congress that authorized removal of sandbars and snags in the Ohio River (paragraphs 80-81). Channelization of the Ohio River was initiated in 1878 with the construction of an experimental lock and movable dam at Davis Island, downstream from Pittsburgh. Improvement of waterways for commercial navigation purposes has become predominantly a Federally sponsored and managed enterprise.

97. The system of navigable waterways in the Ohio River Basin consists of the Ohio River and nine channelized tributaries. In addition, reaches of other tributary streams are navigable for short distances upstream from their mouths due to backwater from Ohio River dams. The total basin system length (minimum of 9-ft navigation depth) is over 2300 miles, with 981 miles on the Ohio River. Completion of the Tennessee-Tombigbee Waterway will further expand this transportation network (paragraph 83). The modernization of Ohio River navigation facilities was initiated by a Federal program in 1954, which provided for replacement of the 46 lock and dam units by 19 high-lift structures and the continued maintenance of the 9-ft channel depth. Although the modernization and replacement program will serve most of the present needs, this program is considered to lag behind projected needs.

98. As part of the channelization program, 9.4 miles of dikes and 13.1 miles of revetment have been placed in the Ohio River Basin. Some 19 percent of the total channel miles in the basin are actively eroding (1979). This erosion results in an annual property loss of $3.8 million and would require $26.4 million to restore the banks to their original condition. Studies[47] conducted to assess the impact on bank erosion of raising the Cannelton and Meldahl navigation pools concluded that the bank erosion would have occurred by natural phenomena without the construction of navigation structures and the impoundment of permanent pools.

## Reservoirs

99. Over one hundred structures have been placed (or are under construction) in the Ohio River Basin that have storage capacities

greater than 75,000 acre-ft (Table D7 and Figures D8 and D9). These impoundments have a collective storage capacity in excess of 52,000,000 acre-ft. The majority of these structures have a flood control function; in addition, many have storage allocated for a summer or all-season recreation pool, water supply, hydroelectric power, low flow augmentation quality control, navigation, and fish and wildlife conservation. Most of the impoundments do not have a sediment retention function. Because of the variety of control structure configurations found throughout the basin and their methods of operation, it is difficult to assess the impact of the reservoirs listed in Table D7 on the suspended-sediment regime of the streams in the Ohio River Basin; however, their effects have undoubtedly reduced suspended sediment loads.

100. Reservoir siltation in the Ohio River Basin is not a major problem as compared to some western areas (e.g. Missouri River Basin). In previous CE reservoir studies,[2] an annual deposition rate of 0.2 to 0.5 acre-ft per square mile of drainage area has been used for design purposes. Sediment surveys conducted throughout the basin indicate that no reservoir design lives are being significantly reduced due to deposition, with the possible exception of reservoirs along the Ocoee River in the Tennessee River Subbasin, and some reservoirs in the eastern part of the basin, where heavy coal mining activity is in progress or is anticipated. A survey[48] conducted at Fishtrap Reservoir in eastern Kentucky indicated a sediment deposition rate seven times that of the design rate.

101. Reservoirs of less than 75,000-acre-ft storage capacity are not included in Table D7, although many such small projects are in operation throughout the basin. Over the years, a multitude of stock dams, fish and recreation lakes, and farm ponds have also been built in the basin to intercept the runoff from small drainage areas. Although the total storage capacity of these impoundments is not accurately known, it has undoubtedly had some effect on the reduction of sediment flow in the Ohio main stem. Included among the small reservoirs are approximately 450 floodwater-retarding structures that have been planned under Public Law 566 in cooperation with the SCS. These dams are currently in

various stages of development and are anticipated to include some 300,000 acre-ft of floodwater storage capacity from approximately 2500 square miles of drainage area.

Mining

102. The increasing demand for coal as an alternative energy source has, no doubt, encouraged an increase in soil losses due to mining activities. Studies in areas where heavy mining is in progress indicate that sediment yields range from 3,000 to 21,000 tons per square mile where surface-mining techniques predominate, and from 750 to 3,500 tons per square mile where underground-mining methods are used. Strip-mining operations often destroy vegetation and forest cover and create spoil banks that are easily eroded. Surface-mining operations are now responsible for less than 10 percent of the basin's coal production; however, as more efficient coal removal processes are required to increase production, surface-mining techniques will be utilized more, causing an attendant escalation of soil losses, and in turn increased stream sediment loads.

## History of Suspended-Sediment Sample Collection

103. The first recorded repetitive collection of suspended-sediment samples in the Ohio River Basin was at Paducah, Ky. (45 miles upstream from Cairo, Ill.). Samples were taken from the Ohio River on a daily basis from 16 Dec 1878 through 30 Dec 1879. Samples were collected from the surface and near the bottom at points one-third and two-thirds of the distance across the river. The surface and bottom specimens were kept in separate jars, each jar containing collections for five days. After settling the clear water was siphoned off and the residue run through filter papers. A complete physical description of the sampling device was not included with the reported documentation. During this period, the maximum daily water discharge was 1,520,863 acre-ft; the mean, 454,511 acre-ft; and the minimum, 39,930 acre-ft. The maximum daily suspended-sediment load was 1,406,147 tons; the mean, 200,020 tons; and the minimum, 2,024 tons. The cumulative sediment discharge through

this period was 15,201,632 tons. These statistics represent the first published long-term data for the basin. The TVA collected samples on a short-term basis at 48 locations during 1935-37.[49] Several of these stations were again activated by TVA in 1962 for a three-year period to assess changes that had occurred during the interim years. In more recent times, the earliest reported long-term operation of a suspended-sediment sample collection station was at Munfordville, Ky., beginning in 1952. Currently, there are 20 stations in the basin having at least a five-year record; none are on the Ohio main stem (a daily station was activated at Louisville on 1 Oct 1979).

104. An inventory of the active and recently active sediment sample collection stations in the Ohio River Basin is provided in "Inventory of Sediment Collection Stations in the Mississippi River Basin" (Reference 50). This reference also includes historic narratives for four sediment sample collection stations located on the Ohio main stem. Although these stations do not have five-year periods of record, narratives for these stations were prepared because operating officials anticipate future sediment sample collection schedules that will provide long-term records. The narratives contain a wide variety of information, including a description of the site where the sediment sample collection station is located, the station chronological record, sample collection procedures, laboratory sample analysis, and data reduction and reporting procedures. Reference 50 provides narratives for the following stations:

Ohio main stem - Greenup Dam, Ky.
Markland Dam, Ky.
Cannelton Dam, Ky.
Dam 53, near Grand Chain, Ill.

105. Much of the suspended-sediment data collected in the Ohio River Basin has been published. No permanent sediment sample collection stations have been operated by the CE in the basin. Suspended-sediment data resulting from samples collected at stations operated by the USGS were reported in Quality of Surface Waters of the United States through 1969 (Reference 51). Beginning in 1961 and continuing through the

present, the data for USGS stations are published as follows: Indiana (Reference 52), Kentucky (Reference 53), Ohio (Reference 54), Pennsylvania (Reference 55), and West Virginia (Reference 56). Before 1961, discharge data for the USGS stations were published in Surface Water Supply of the United States (Reference 57). After 1961, discharge data for the USGS stations were published as follows: Indiana (Reference 58), Kentucky (Reference 59), Ohio (Reference 60), Pennsylvania (Reference 61), and West Virginia (Reference 62). No permanent sediment sample collection stations have been operated by the USGS in those portions of Alabama, Georgia, Illinois, Maryland, Mississippi, New York, North Carolina, Tennessee, and Virginia that lie in the Ohio River Basin.

106. Using the available inventories and data sources noted above, annual (water year) data for each known sediment sample collection station in the Ohio River Basin were tabulated. These data included: discharge (acre-ft), suspended-sediment load (tons), and maximum daily suspended-sediment load occurring during the water year (tons). A listing of all stations having at least a five-year record is provided in Table D8. The station locations are shown on a basin map (Figure D8) and on a linear streamflow diagram (Figure D9); data for these stations are presented in Figures D10-D27 (presented in the same order as listed in Table D8). In order that a year of record be accepted as valid for a station where daily suspended-sediment samples were not taken, the following criterion was used: samples must have been taken on at least ten days during each month of the year when there was flow; the available data was then adjusted to an annual basis.

## Long-Term Trends in Suspended-Sediment Regime

107. The limited amount of suspended-sediment data available in the Ohio River Basin makes the identification of long-term trends difficult. Under natural conditions, the Ohio River contributed 60 percent of the discharge of the Lower Mississippi River immediately downstream from the confluence of the Ohio with the Upper Mississippi, however, not a proportional amount of suspended sediment. The character of the soil

loss regime in the Ohio River Basin is such that estimated suspended-sediment loads in the streams of this drainage are small compared to the loads measured in the Missouri and Upper Mississippi Basins. The placement of a series of sediment retention structures in the Missouri River Basin (1953-1967) has been largely responsible for reducing the suspended-sediment load in the Upper Mississippi at St. Louis by 64 percent, and probably by the same factor, the Upper Mississippi's contribution to the Lower Mississippi load. Thus, the contribution of the Ohio may now represent a significant proportion of the total suspended-sediment load downstream from the Upper Mississippi-Ohio confluence (see Appendix F).

108. The results of a TVA study[49] have indicated an overall reduction in suspended-sediment loads from 1935-1937 to 1963-1965 (paragraph 103), which can be attributed to greatly improved land management practices that have gone into effect throughout the Tennessee Valley since 1935. Improved farming practices such as the use of winter cover crops, contour planting, field terracing, and the conversion of hill land from row crops to permanent pasture have all reduced erosion and lowered or delayed surface runoff, thus reducing the amount of soil carried into the streams. Reforestation of idle and eroded land, improvement in forest fire control, and the reduction in woodland grazing have also contributed significantly to the reduction of erosion in the Tennessee River drainage.

## PART IV: CHARACTERIZATION OF BED-MATERIAL GRADATION

109. The streams flowing through the eastern and southern portion of the Ohio River Basin originate in mountainous areas. The upper reaches of these streams have steep slopes that permit the rapid transport of available coarse and fine material. In these higher elevations, the rocks are well indurated and only slightly affected by stream action. Below the 1000-ft elevation contour in the area between the Tennessee and Ohio Rivers are the softer Carboniferous limestones. These limestones are highly susceptible to the erosive action of the streams that contribute to the bedload of the Ohio River.[63] When the material reaches the main stem of the Ohio, the reduced gradients and increased discharges result in a progressive sorting of the total sediment load, as a portion of the suspended load settles to the bottom to become part of the bedload. The glaciated area north of the Ohio River, through which most of the right-bank tributaries flow, is also a significant source area for main-stem bed material.

### Cultural Influences on Bed-Material Gradation

110. The major cultural influences on the bed-material gradation of the streams in the Ohio River Basin have been channel improvements (paragraphs 96-98), reservoir construction (paragraphs 99-101), mining (paragraph 102), and dredging. In addition, agricultural practices affect the gradation of bed material to some degree, but their influence has been lessened since the advent of the soil conservation measures of the 1930's.

111. Dredging is necessary to maintain navigation in the Ohio, Tennessee, Cumberland, Allegheny, and Monongahela Rivers. Dredges are used in those reaches where the navigation channel depth is jeopardized by shoaling due either to natural or man made causes. This activity is the responsibility of the four Districts that comprise the CE Ohio River Division--Huntington, Louisville, Nashville, and Pittsburgh. Table D9 provides maintenance dredging records for these four Districts

covering the period since fiscal year 1968.

112. Environmental constraints have generally brought about a reduction in dredging volumes. In addition to continually escalating unit dredging costs, the expenses incurred for hydrographic surveys, preparation of environmental impact statements, construction of disposal sites, and court costs are usually taken out of a District's dredging budget. Thus, a lesser percentage of each subsequent year's funding is available for actual dredging operations. Material removed from the main stem of the Ohio River represents the bulk of maintenance dredging in the basin. Most of this has been concentrated in the reach that includes the Louisville District. Unit costs by districts are as follows:

| District | Current (1978) Cost per cubic yard |
|---|---|
| Huntington | $1.65 |
| Louisville | 0.91 |
| Nashville | 2.18 |
| Pittsburgh | 4.00 |

## History of Bed-Material Sample Collection

113. Records of the avai``ble bed-material sample collection stations in the basin were examined to determine if they met either of the following criteria:

- a. A 10-year continuous record during which five or more gradation samples were taken on at least 30 days during the period.
- b. At least two years of continuous record averaging at least five days per year on which five or more samples were taken.

No station met either of these criteria, which have been used throughout this study; therefore, no bed-material gradation envelopes were constructed.

114. A limited CE bed-material sampling program (1975) conducted on the Ohio River downstream from mile 700 showed that 99 percent of the material would not pass a U. S. Standard Number 200 sieve,

meaning that very little silt or clay was present in the lower river. Commercial dredge operators working below mile 800 indicate that more than 90 percent of the mined material is sand. (The majority of this sand is classified as "coarse" or concrete sand.) Most companies do not consider gravel mining economically feasible. Opinions differ among dredge operators as to changes in the bed-material gradation over past years in the Lower Ohio River; some say no changes have taken place, while others think the limited gravel supply has declined. Regardless of the difference in opinions, the bed-material contribution of the Ohio to the Lower Mississippi main stem is not becoming more coarse.

115. Gravel mining upstream from Louisville is profitable. Dredging companies operating from Ohio River mile 500 to 600 report that 20 to 30 percent of the removed material is gravel. Available coarse sand ranges from 40 to 65 percent and medium sand 20 to 30 percent. Further upstream the percentage of gravel continues to increase. Dredge operators working from mile 0 through mile 300 report equal amounts of sand and gravel are generally available for removal. Collectively, dredge operators tend to think that there have been no major changes in the Upper Ohio River bed-material gradation, except for reaches in the immediate vicinity of control structures and mined areas where siltation has occurred.

## Long-Term Trends in Bed-Material Gradation

116. Future changes in the bed-material gradation of the streams in the Ohio River Basin can probably be attributed to continued adjustments made to existing channel improvements and reservoirs and to any new engineering adjustments made to the main stem and its tributaries. The lower reaches of the Ohio River will continue to require the bulk of the maintenance dredging. Surface mining may provide a major bed-material supply source, unless properly controlled.

## PART V: SUMMARY

117. The limited amount of suspended-sediment data available in the Ohio River Basin makes the identification of long-term trends difficult. Under natural conditions, the Ohio River contributed 60 percent of the discharge of the Lower Mississippi River immediately downstream from the confluence of the Ohio with the Upper Mississippi River; however, not a proportional amount of suspended sediment. The character of the soil loss regime in the Ohio River Basin is such that estimated suspended-sediment loads in the streams of this drainage are small (although increasing) compared to the loads measured in the Missouri and Upper Mississippi Basins. The placement of a series of sediment retention structures in the Missouri River Basin (1953-1967) has been largely responsible for reducing the suspended-sediment load in the Upper Mississippi at St. Louis by 64 percent, and probably by the same factor, the Upper Mississippi's contribution to the Lower Mississippi load. Thus, the contribution of the Ohio may now represent a significant proportion of the total suspended-sediment load downstream from the Upper Mississippi-Ohio confluence (see Appendix F).

118. No long-term bed-material gradation data are available for the Ohio River Basin. A limited CE bed-material sampling program (1975) conducted on the Ohio River downstream from mile 700 showed that 99 percent of the material would not pass a U. S. Standard Number 200 sieve, meaning that very little silt or clay was present in the lower river. Commercial dredge operators working below mile 800 indicate that more than 90 percent of the mined material is sand. (The majority of this sand is classified as "coarse" or concrete sand.) Opinions differ among dredge operators as to changes in the bed-material gradation over past years in the Lower Ohio River; some say no changes have taken place, while others think the limited gravel supply has declined. Regardless of the difference in opinions, the bed-material contribution of the Ohio to the Lower Mississippi main stem is not becoming more coarse. Dredge operators working upstream from Louisville tend to think that there have been no major changes in the Upper Ohio River bed-material gradation,

except for reaches in the immediate vicinity of control structures and mined areas where siltation has occurred.

119. Future changes in the bed-material gradation of the streams in the Ohio River Basin can probably be attributed to continued adjustments made to the existing channel improvements and reservoirs and to any new engineering adjustments made to the main stem and its tributaries. The lower reaches of the Ohio River will continue to require the bulk of the maintenance dredging. Surface mining may provide a major bed-material supply source, unless properly controlled.

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Table D1

Subbasins - Ohio River Basin

| Subbasin | Area, $mi^2$ | Elevations, ft Minimum | Elevations, ft Maximum | Average Annual Precipitation in. |
|---|---|---|---|---|
| Allegheny River | 11,700 | 710 | 2500 | 40 |
| Big Sandy-Guyandotte Rivers | 5,950 | 515 | 2485 | 43 |
| Cumberland River | 17,920 | 302 | 4150 | 50 |
| Great Miami River | 5,400 | 455 | 1183 | 38 |
| Green River | 9,230 | 337 | 1285 | 48 |
| Kanawha River | 12,200 | 538 | 5700 | 45 |
| Kentucky-Licking Rivers | 10,640 | 421 | 2165 | 41 |
| Lower Ohio River | 12,570 | 300 | 1095 | 45 |
| Middle Ohio River | 9,050 | 421 | 1365 | 41 |
| Monongahela River | 7,380 | 710 | 4600 | 40 |
| Muskingum River | 8,040 | 582 | 1306 | 39 |
| Scioto River | 6,510 | 485 | 1550 | 38 |
| Tennessee River | 40,910 | 302 | 6684 | 42 |
| Upper Ohio River | 13,380 | 538 | 4862 | 43 |
| Wabash River | 33,100 | 320 | 1257 | 40 |
| Total | 203,980 | | | |

Table D2

Ohio River Basin Water Use and Projected Requirements*

| Type of Use | Daily Requirements million gallons | | | | Daily Requirements million gallons | | | |
|---|---|---|---|---|---|---|---|---|
| | Used 1965 | 1980** | 2000 | 2020 | Used 1965 | 1980** | 2000 | 2020 |
| | Withdrawals | | | | Consumptive Uses | | | |
| Municipal | 1,743 | 2,305 | 3,292 | 4,777 | 174 | 231 | 329 | 478 |
| Manufacturing industries | 9,811 | 11,730 | 16,065 | 23,480 | 196 | 235 | 321 | 470 |
| Electric power cooling | 19,200 | 29,000 | 46,000 | 63,000 | 158 | 356 | 705 | 1,240 |
| Mining | 289 | 511 | 974 | 1,894 | 53 | 79 | 133 | 244 |
| Rural non-farm domestic | 587 | 673 | 794 | 934 | 391 | 449 | 530 | 623 |
| Agriculture: | | | | | | | | |
| Farm domestic | 46 | 39 | 37 | 36 | 46 | 39 | 37 | 36 |
| Irrigation | 46 | 102 | 352 | 682 | 46 | 102 | 352 | 682 |
| Livestock | 116 | 129 | 194 | 258 | 116 | 129 | 194 | 258 |
| Total | 31,838 | 44,489 | 67,708 | 95,061 | 1,180 | 1,620 | 2,601 | 4,031 |

* Data adapted from Reference 1.
** Projected values for 1980, 2000, and 2020.

Table D3

1977 Freight and Passenger Traffic in the Ohio River Basin*

| Stream | Reach | Freight Traffic short tons | No. of Passengers |
|---|---|---|---|
| Allegheny River | Pittsburgh to East Brady, Pa. (mile 72) | 5,084,990 | |
| Barkley Canal (Connecting Cumberland and Tennessee Rivers) | Entire 1.75-mile length | 4,749,032 | 350 |
| Big Sandy River; Tug Fork; Levisa Fork | Mouth to mile 26.83; mile 0 to mile 12.47; mile 0 to mile 17.47 | 1,282,480 | |
| Cumberland River | Mouth to Nashville (mile 194) | 12,756,429 | 114,168 |
| | Nashville to mile 552 | 368,667 | 88,050 |
| Green River; Barren River | Mouth to Mammoth Cave (mile 197.8); mouth to Bowling Green, Ky. (mile 30.1) | 13,501,167 | |
| Hiwassee River | | 676,750 | |
| Kanawha River | Mouth to mile 90.57 | 10,755,599 | |
| Kentucky River | Mouth to confluence of North and South forks (mile 254.7) | 465,116 | 268 |
| Little Kanawha River | | 143,499 | |
| Monongahela River | Pittsburgh to Fairmont, W. Va. (mile 128.7) | 34,420,145 | 4,140 |
| Muskingum River | | 5,600 | |
| Ohio River | Pittsburgh to mouth (mile 981) | 151,402,617 | 357,100 |
| Tennessee River | Mouth to Knoxville (mile 650) | 26,583,240 | 62,572 |

* Data adapted from Reference 14.

Table D4

Selected Cities in the Ohio River Basin and Dates Settled

| City | Date Settled |
|---|---|
| Pittsburgh, Pa. | 1758 |
| Wheeling, W. Va. | 1769 |
| Louisville, Ky. | 1778 |
| Akron, Ohio | 1779 |
| Nashville, Tenn. | 1779 |
| Lexington, Ky. | 1780 |
| Knoxville, Tenn. | 1786 |
| Cincinnati, Ohio | 1788 |
| Fort Wayne, Ind. | 1794 |
| Dayton, Ohio | 1796 |
| Stubenville, Ohio | 1797 |
| Columbus, Ohio | 1797 |
| Huntsville, Ala. | 1805 |
| Evansville, Ind. | 1812 |
| Ashland, Ky. | 1815 |
| Chattanooga, Tenn. | 1815 |
| Indianapolis, Ind. | 1821 |
| Paducah, Ky. | 1821 |

Table D5

Land-Use Data - Ohio River Basin

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest * | Other Land* | Total Land Area |
| | | 1860 | | | |
| Alabama | 861,143 | 1,715,769 | 1,850,832 | | 4,427,744 |
| Georgia | 237,045 | 546,479 | 225,416 | | 1,008,940 |
| Illinois | 2,707,021 | 1,615,488 | 3,091,773 | | 7,414,282 |
| Indiana | 6,831,121 | 6,751,495 | 5,536,191 | | 19,118,807 |
| Kentucky | 7,467,627 | 11,252,963 | 6,401,066 | | 25,121,656 |
| Maryland | 46,140 | 76,974 | 173,014 | | 296,128 |
| Mississippi | 47,112 | 100,198 | 127,877 | | 275,187 |
| New York | 581,515 | 267,970 | 384,532 | | 1,234,017 |
| North Carolina | 751,443 | 1,988,427 | 856,196 | | 3,596,066 |
| Ohio | 9,123,110 | 5,670,059 | 4,047,584 | | 18,840,753 |
| Pennsylvania | 3,662,154 | 2,292,095 | 4,087,150 | | 10,041,399 |
| Tennessee | 5,527,327 | 11,284,972 | 4,888,475 | | 21,700,774 |
| Virginia | 4,857,643 | 8,357,763 | 4,256,041 | | 17,471,447 |
| Total | 42,700,401 | 51,920,652 | 35,926,147 | | 130,547,200 |
| | (32.71%) | (39.77%) | (27.52%) | | |

(Continued)

* Forest and other land categories were not surveyed separately for the 1860 census (Reference 45).

(Sheet 1 of 4)

Table D5 (Continued)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | | 1910 | | |
| Alabama | 1,494,586 | 120,866 | 1,527,082 | 1,285,210 | 4,427,744 |
| Georgia | 234,066 | 95,085 | 367,053 | 312,736 | 1,008,940 |
| Illinois | 5,797,817 | 82,205 | 723,853 | 810,407 | 7,414,282 |
| Indiana | 14,092,979 | 731,495 | 2,927,697 | 1,366,636 | 19,118,807 |
| Kentucky | 13,923,262 | 877,185 | 6,860,404 | 3,460,805 | 25,121,656 |
| Maryland | 82,623 | 13,163 | 83,364 | 116,978 | 296,128 |
| Mississippi | 64,474 | 14,728 | 126,366 | 69,619 | 275,187 |
| New York | 659,091 | 148,345 | 224,538 | 202,043 | 1,234,017 |
| North Carolina | 881,844 | 89,752 | 1,417,732 | 1,206,738 | 3,596,066 |
| Ohio | 13,930,406 | 1,130,766 | 2,437,153 | 1,342,438 | 18,840,753 |
| Pennsylvania | 4,612,470 | 740,145 | 1,343,896 | 3,344,888 | 10,041,399 |
| Tennessee | 8,382,934 | 842,767 | 6,817,797 | 5,657,276 | 21,700,774 |
| Virginia | 1,780,148 | 169,477 | 1,302,440 | 944,532 | 4,196,597 |
| West Virginia | 4,805,951 | 423,619 | 3,226,902 | 4,818,378 | 13,274,850 |
| Total | 70,742,651 | 5,479,598 | 29,386,277 | 24,938,674 | 130,547,200 |
| | (54.19%) | (4.20%) | (22.51%) | (19.10%) | |

(Continued)

Table D5 (Continued)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1935 | | | |
| Alabama | 1,426,458 | 506,741 | 1,169,240 | 1,325,305 | 4,427,744 |
| Georgia | 123,914 | 84,377 | 341,305 | 459,344 | 1,008,940 |
| Illinois | 3,546,748 | 1,853,858 | 610,645 | 1,403,031 | 7,414,282 |
| Indiana | 8,462,953 | 4,738,151 | 2,686,270 | 3,231,433 | 19,118,807 |
| Kentucky | 5,299,880 | 7,994,951 | 2,748,681 | 9,078,144 | 25,121,656 |
| Maryland | 39,259 | 38,674 | 78,406 | 139,789 | 296,128 |
| Mississippi | 60,227 | 23,594 | 85,754 | 105,612 | 275,187 |
| New York | 308,051 | 366,902 | 214,170 | 344,894 | 1,234,017 |
| North Carolina | 365,316 | 508,706 | 969,657 | 1,752,387 | 3,596,066 |
| Ohio | 6,812,553 | 6,356,789 | 2,421,425 | 3,249,986 | 18,840,753 |
| Pennsylvania | 2,071,256 | 1,915,009 | 1,295,956 | 4,759,178 | 10,041,399 |
| Tennessee | 4,635,407 | 4,257,268 | 5,275,157 | 7,532,942 | 21,700,774 |
| Virginia | 575,147 | 1,270,156 | 995,688 | 1,355,606 | 4,196,597 |
| West Virginia | 1,463,218 | 3,257,012 | 2,877,969 | 5,676,651 | 13,274,850 |
| Total | 35,190,387 | 33,172,188 | 21,770,323 | 40,414,302 | 130,274,850 |
| | (26.96%) | (25.41%) | (16.67%) | (30.96%) | |

(Continued)

(Sheet 3 of 4)

Table D5 (Concluded)

| State | Land Use, acres: Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
|---|---|---|---|---|---|
| | | | 1967 | | |
| Alabama | 1,310,588 | 611,184 | 1,848,917 | 657,055 | 4,427,744 |
| Georgia | 70,269 | 116,987 | 489,012 | 332,672 | 1,008,940 |
| Illinois | 4,606,747 | 764,143 | 997,672 | 1,045,720 | 7,414,282 |
| Indiana | 10,941,642 | 2,024,657 | 3,604,761 | 2,547,747 | 19,118,807 |
| Kentucky | 5,266,076 | 6,298,189 | 10,532,300 | 3,025,091 | 25,121,656 |
| Maryland | 49,131 | 32,449 | 156,306 | 58,242 | 296,128 |
| Mississippi | 50,849 | 20,976 | 187,160 | 16,202 | 275,187 |
| New York | 290,877 | 174,726 | 666,458 | 101,956 | 1,234,017 |
| North Carolina | 259,944 | 476,270 | 1,966,372 | 893,478 | 3,596,066 |
| Ohio | 7,971,253 | 2,870,942 | 5,025,163 | 2,973,395 | 18,840,753 |
| Pennsylvania | 2,076,052 | 829,519 | 4,931,624 | 2,204,204 | 10,041,399 |
| Tennessee | 3,442,283 | 3,974,424 | 10,706,337 | 3,577,730 | 21,700,774 |
| Virginia | 474,662 | 1,187,829 | 2,389,339 | 144,767 | 4,196,597 |
| West Virginia | 868,335 | 1,567,110 | 8,857,048 | 1,982,357 | 13,274,850 |
| Total | 37,678,708 | 20,949,407 | 52,358,469 | 19,560,616 | 130,547,200 |
| | (28.86%) | (16.05%) | (40.11%) | (14.98%) | |

(Sheet 4 of 4)

Table D6

Estimated Annual Sediment Yield of Subbasins in the Ohio River Basin*

| Subbasin | Area, $mi^2$ | Unit Annual Sediment Yield, $tons/mi^2$ | Annual Sediment Yield tons |
|---|---|---|---|
| Allegheny River | 11,700 | 646 | 7,558,200 |
| Big Sandy and Guyandotte Rivers | 5,950 | 1,187 | 7,062,650 |
| Cumberland River | 17,920 | 523 | 9,372,160 |
| Great Miami River | 5,400 | 1,124 | 6,069,600 |
| Green River | 9,230 | 922 | 8,510,060 |
| Kanawha River | 12,200 | 421 | 5,136,200 |
| Kentucky-Licking Rivers | 10,640 | 988 | 10,512,320 |
| Lower Ohio River | 12,570 | 967 | 12,155,190 |
| Middle Ohio River | 9,050 | 701 | 6,344,050 |
| Monongahela River | 7,380 | 404 | 2,981,520 |
| Muskingum River | 8,040 | 414 | 3,328,560 |
| Scioto River | 6,510 | 511 | 3,326,610 |
| Tennessee River | 40,910 | 931 | 38,087,210 |
| Upper Ohio River | 13,380 | 586 | 7,840,680 |
| Wabash River | 33,100 | 789 | 26,115,780 |
| Ohio River Basin | 203,980 | 757 | 154,400,790 |

* Subbasin estimates were computed on an areal basis using unit sediment yields determined from reservoir survey file information provided by the U. S. Army Engineer District, Ohio River. These estimates are cumulative sums and do not reflect measures that have been taken to minimize stream sediment loads (i.e., impoundments, dikes, soil conservation practices, etc.); nor do the estimates account for sediment originating in upstream areas outside the subbasin that eventually must pass through the subbasin. Thus, the estimates provided in this table more properly reflect the potential areal yields of the subbasins rather than actual yields.

Table D7

Dams - Ohio River Basin*

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Contributing Drainage Area, $mi^2$ Current** (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Allegheny River | Allegheny River | Kinzua | | 1967 | 2,180 | | 1,180,000 | | | | | CE |
| | Clarion River | Foxburg | | 1935 | | | 115,200 | | | | | Clarion River Power Co. |
| | | Mill Creek | | 1929 | | | 852,000 | | | | | Clarion River Power Co. |
| | Conemaugh River | Conemaugh | | 1952 | 1,351 | | 274,000 | 1966 | | 391 | | CE |
| | Crooked Creek | Crooked Creek | | 1940 | 277 | | 93,900 | 1964 | | 64 | | CE |
| | East Branch Clarion River | East Branch Clarion | | 1952 | 72.4 | | 84,300 | 1971 | | 46 | | CE |
| | Loyalhanna Creek | Loyalhanna | | 1942 | 290 | 285 | 95,300 | Apr 1962 | 93,500 | 81 | 77,500 | CE |
| | Plum Creek (North Branch) | Keystone Station | | 1965 | | | 168,400 | | | | | Keystone Station Owners |
| | Tionesta Creek | Tionesta | | 1940 | 478 | 474 | 133,400 | May 1971 | 132,400 | 9 | 14,700 | CE |
| | Yellow Creek | Yellow Creek State Park | | 1972 | | | 975,000 | | | | | Pa. Dept. of Forests and Water Resources |
| Big Sandy-Guyandotte Rivers | Guyandotte River | R. D. Bailey | | Under construction | 540 | | 203,700 | | | | | CE |
| | Johns Creek | Dewey | | 1950 | 207 | | 93,300 | 1975 | | 146 | | CE |
| | Levisa Fork | Fishtrap | | 1969 | 395 | 388 | 164,400 | 1975 | | 464 | | CE |
| | Pound River | John W. Flannagan | | 1963 | 221 | 204 | 145,700 | 1974 | | 92 | | CE |
| Cumberland River | Caney Fork | Center Hill | 26.6 | 1948 | 2,174 | | 2,092,000 | | | | | CE |

(Continued)

* With design storage capacities ≥ 75,000 acre-ft.
** Current (1977) contributing drainage areas include many small catchment structures whose retention efficiencies have not been inventoried.
† CE - Corps of Engineers, MCD - Miami Conservancy District, TVA - Tennessee Valley Authority.

(Sheet 1 of 6)

Table D7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumberland River (Cont'd) | Cumberland River | Barkley | 30.6 | 1966 | 17,598 | | 2,082,000 | | | | | CE |
| | | Cheatham | 148.7 | 1959 | 14,160 | | 104,000 | | | | | CE |
| | | Old Hickory | 216.2 | 1957 | 11,674 | 2,741 | 545,000 | Jun 1965 | | 1,209 | | CE |
| | | Cordell Hull | 313.5 | 1973 | 8,096 | | 310,900 | | | | | CE |
| | | Wolf Creek (Lake Cumberland) | 460.9 | 1950 | 5,789 | 5,690 | 6,089,000 | Jun 1963 | | | | CE |
| | Laurel River | Laurel | 2.3 | 1977 | 282 | | 435,600 | | | | | CE |
| | Obey River | Dale Hollow | 7.3 | 1943 | 935 | 887 | 1,706,000 | Jun 1960 | | | | CE |
| | Stones River | J. Percy Priest | 6.8 | 1967 | 892 | | 652,000 | | | | | CE |
| Great Miami River | Great Miami River | Taylorsville | | 1922 | | | 386,000 | | | | | MCD |
| | Loramie Creek | Lockington (Lake Loramie) | | 1922 | | | 126,000 | | | | | MCD |
| | Mad River | Huffman | | 1922 | | | 297,000 | | | | | MCD |
| | Stillwater Creek | Englewood | | 1922 | 651 | 639 | 413,000 | 1942 | 311,700 | 24 | 40,300 | MCD |
| | Twin Creek | Germantown | | 1922 | 270 | 264 | 106,000 | 1942 | 105,600 | 26 | 44,400 | MCD |
| | Whitewater River (East Fork) | Brookville | | 1974 | 379 | | 359,600 | | | | | CE |
| Green River | Barren River | Barren River | | 1964 | 940 | | 815,200 | | | | | CE |
| | Green River | Green River | | 1969 | 682 | | 723,200 | | | | | CE |
| | Nolin River | Nolin | | 1963 | 703 | | 609,400 | | | | | CE |
| | Rough River | Rough River | | 1960 | 454 | 438 | 334,400 | Jul 1969 | 331,200 | 337 | 511,900 | CE |
| Kanawha River | Elk River | Sutton | | 1960 | 537 | 531 | 265,300 | Jan 1973 | 264,700 | 85 | 111,000 | CE |
| | Gauley River | Summersville | | 1964 | 803 | | 413,400 | | | | | CE |
| | New River | Bluestone | | 1949 | 4,565 | 2,221 | 631,000 | May 1965 | 625,800 | 333 | 399,800 | CE |
| | | Claytor | | 1939 | 2,382 | | 2,320,000 | | | | | AEPCO |

(Continued)

(Sheet 2 of 6)

Table D7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Contributing Drainage Area, $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kentucky-Licking Rivers | Dix River | Dix (Herrington Dam) | | 1925 | 437 | 431 | 320,000 | Oct 1941 | 255,700 | 203 | | Kentucky Utilities Co. |
| | Kentucky River (Middle Fork) | Buckhorn | | 1961 | 408 | | 167,400 | 1967 | | 167 | | CE |
| | Licking River | Cave Run | | 1974 | 826 | | 614,100 | | | | | CE |
| Lower Ohio | Salt River | Taylorsville | | Under construction | 353 | | 291,700 | | | | | CE |
| Middle Ohio River | Caesar Creek | Caesar Creek | | 1978 | 237 | | 242,200 | | | | | CE |
| | East Fork | East Fork | | 1978 | 342 | | 294,800 | | | | | CE |
| | Little Sandy River | Grayson | | 1969 | 196 | | 119,000 | | | | | CE |
| | Twelvepole Creek (East Fork) | East Lynn | | 1972 | 133 | | 82,500 | | | | | CE |
| Monongahela River | Deep Creek | Deep Creek Hydroelectric | | 1925 | | | 127,200 | | | | | Pennsylvania Electric Co. |
| | Tygart River | Tygart | | 1938 | 1,184 | 1,179 | 289,600 | Mar 1959 | 287,700 | 94 | 125,000 | CE |
| | Youghiogheny River | Youghiogheny | | 1948 | 434 | 428 | 254,000 | Oct 1973 | 248,100 | 210 | 220,900 | CE |
| Muskingum River | Black Fork | Charles Mill | | 1936 | 215 | 207 | 88,000 | 1975 | | 14 | | CE |
| | Clear Fork | Pleasant Hill | | 1938 | 197 | 195 | 87,700 | Feb 1945 | 87,400 | 44 | 62,600 | CE |
| | Lake Fork | Mohicanville | | 1937 | 271 | | 102,000 | | | | | CE |
| | Licking River | Dillon | | 1961 | 742 | | 274,000 | 1973 | | 126 | | CE |
| | Salt Fork | Salt Fork | | 1968 | | | 120,000 | | | | | State of Ohio |
| | Sandy Creek | Bolivar | | 1938 | 502 | | 149,600 | | | | | CE |
| | Seneca Fork | Senecaville | | 1937 | 118 | 113 | 88,500 | Mar 1945 | 87,700 | 101 | | CE |
| | Tuscarawas River | Dover | | 1938 | 1,397 | 782 | 203,000 | | | | | CE |

(Continued)

(Sheet 3 of 6)

Table D7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Contributing Drainage Area, $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Muskingum River (Cont'd) | Walhonding River | Mohawk | | 1937 | 1,504 | 821 | 285,000 | | | | | CE |
| | Wills Creek | Wills Creek | | 1937 | 842 | 724 | 196,000 | 1973 | | 80 | | CE |
| Scioto River | Alum Creek | Alum Creek | | 1974 | 123 | | 134,800 | | | | | CE |
| | Big Walnut Creek | Hoover | | 1956 | | | 90,000 | | | | | City of Columbus, Ohio |
| | Deer Creek | Deer Creek | | 1968 | 277 | | 102,500 | 1975 | | 22 | | CE |
| | Olentangy River | Delaware | | 1948 | 381 | | 132,000 | 1975 | | 38 | | CE |
| | Paint Creek | Paint Creek | | 1974 | 573 | | 145,000 | | | | | CE |
| | Rocky Fork | Rocky Fork | | 1954 | | | 86,000 | | | | | State of Ohio |
| Tennessee River | Cedar Creek | Cedar Creek | 23.1 | 1979 | 179 | | 111,500 | | | | | TVA |
| | Cheoh River | Santeetlah | 9.3 | 1926 | 176 | | 271,300 | | | | | TAPOCO, Inc. |
| | Clinch River | Melton Hill | 23.1 | 1963 | 3,343 | 422 | 126,000 | May 1970 | 125,600 | 46 | 55,300 | TVA |
| | | Norris | 79.8 | 1936 | 2,912 | 2,823 | 2,552,000 | Jun 1970 | 2,036,300 | 861 | 1,033,200 | TVA |
| | Duck River | Columbia | 136.9 | Under construction | 1,181 | | 363,000 | | | | | TVA |
| | | Normandy | 248.6 | 1976 | 195 | | 134,000 | | | | | TVA |
| | Elk River | Tims Ford | 133.3 | 1970 | 529 | | 325,400 | | | | | TVA |
| | | Woods Reservoir | 170.0 | 1953 | 263 | | 88,100 | | | | | U. S. Air Force |
| | French Broad | Douglas | 32.3 | 1943 | 4,541 | 2,854 | 1,551,900 | Aug 1967 | 1,475,400 | 2,018 | 2,417,300 | TVA |
| | Hiwassee River | Hiwassee | 75.8 | 1940 | 968 | 539 | 434,000 | May 1965 | 433,600 | 98 | 117,500 | TVA |
| | | Chatuge | 121.0 | 1942 | 214 | 178 | 242,300 | Apr 1965 | 240,500 | 105 | 125,900 | TVA |
| | Holston River | Cherokee | 52.3 | 1941 | 3,428 | 1,477 | 1,559,600 | Jun 1964 | 1,544,000 | 408 | 488,900 | TVA |
| | Holston River (South Fork) | Boone | 18.6 | 1952 | 1,840 | 622 | 193,500 | Sep 1964 | 193,400 | 323 | 387,500 | TVA |
| | | South Holston | 49.3 | 1950 | 703 | 691 | 764,000 | Aug 1964 | | 422 | 505,800 | TVA |

(Continued)

(Sheet 4 of 6)

Table D7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Contributing Drainage Area, $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | *Responsible Agency* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tennessee River (Cont'd) | Little Tennessee River | Tellico | 0.3 | 1980 | 2,627 | | 447,300 | | | | | TVA |
| | | *Fontana* | 61.0 | 1944 | 1,571 | 1,426 | 1,455,100 | Oct 1967 | 1,443,300 | 607 | 728,700 | TVA |
| | Nantahala River | Nantahala (Aquone Lake) | 22.8 | 1942 | 108 | 88 | 138,700 | May 1969 | 137,200 | 67 | 80,200 | Nantahala Power & Light Co. |
| | Nottely River | Nottely | 21.0 | 1942 | 214 | 207 | 174,300 | Apr 1965 | 174,400 | 18 | 21,500 | TVA |
| | Ocoee River | Ocoee No. 1 | 11.9 | 1911 | 595 | 96 | 86,500 | Apr 1968 | 86,500 | 39 | 54,300 | TVA |
| | Tennessee River | Kentucky | 22.4 | 1944 | 40,200 | 7,131 | 6,129,000 | Oct 1961 | | 4,528 | 3,319,200 | TVA |
| | | Pickwick Landing | 206.7 | 1938 | 32,820 | 1,997 | 1,130,300 | Aug 1961 | 1,105,300 | 2,223 | 2,566,145 | TVA |
| | | Wilson | 259.4 | 1924 | 30,750 | 1,135 | 687,000 | Aug 1961 | 641,000 | 1,446 | 1,609,600 | TVA |
| | | Wheeler | 274.9 | 1936 | 29,590 | 5,033 | 1,071,000 | Aug 1961 | 1,050,300 | 2,099 | 2,516,500 | TVA |
| | | Guntersville | 349.0 | 1939 | 24,450 | 2,550 | 1,097,400 | Jul 1961 | 1,064,200 | 1,752 | 2,098,600 | TVA |
| | | Nickajack | 424.7 | 1967 | 21,870 | | 252,400 | | | | | TVA |
| | | Chickamauga | 471.0 | 1940 | 20,790 | 1,805 | 739,000 | Jun 1961 | 738,800 | 303 | 397,100 | TVA |
| | | Watts Bar | 592.9 | 1942 | 17,310 | 2,925 | 1,175,000 | Jun 1961 | 1,175,000 | 1,723 | 2,066,000 | TVA |
| | | Fort Loudon | 602.3 | 1943 | 9,550 | 1,556 | 393,000 | May 1961 | 392,700 | 1,085 | 1,255,700 | TVA |
| | Toccoa River | Blue Ridge (Toccoa Lake) | 53.0 | 1930 | 232 | 227 | | Apr 1968 | 195,900 | 70 | 83,500 | TVA |
| | Watauga River | Watauga | 36.7 | 1948 | 468 | 458 | 677,000 | Aug 1964 | 568,800 | 197 | 235,900 | TVA |
| Upper Ohio River | Mahoning River | Berlin | | 1943 | 249 | | 91,200 | 1951 | | 324 | | CE |
| | Mahoning River (West Branch) | Michael J. Kirwin | | 1967 | 80.5 | | 78,700 | | | | | CE |
| | Mosquito Creek | Mosquito Creek | | 1944 | 97.4 | | 104,100 | | | | | CE |
| | Ohio River | Hannibal Locks and Dam | 126.4 | 1974 | | | 130,000 | | | | | CE |
| | | Pike Island Locks and Dam | 84.2 | 1965 | | | 89,300 | | | | | CE |

(Continued)

(Sheet 5 of 6)

Table D7 (Concluded)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Contributing Drainage Area, $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Ohio River (Cont'd) | | New Cumberland Locks and Dam | 54.4 | 1963 | | | 75,000 | | | | | CE |
| | Shenago River | Shenago | | 1967 | 589 | 431 | 192,400 | | | | | CE |
| | | Pymatuning Reservoir | | 1933 | 158 | | 227,100 | | | | | Pa. Dept. of Envir Resources |
| Wabash River | Beaver Creek | Western Embankment (Grand Lake) | | 1845 | | | 177,000 | | | | | State of Ohio |
| | Mill Creek | Cagles Mill (Cataract Lake) | | 1952 | 295 | 295 | 228,100 | Feb 1962 | 231,000 | 155 | 212,000 | CE |
| | Mississinewa River | Mississinewa | | 1968 | 809 | | 368,400 | | | | | CE |
| | Patoka River | Patoka | | 1978 | 168 | | 301,600 | | | | | CE |
| | Rac[illegible] Creek | Cecil M. Harden | | 1960 | 216 | | 132,800 | 1966 | | 56 | | CE |
| | Sal[illegible] | Salamonie | | 1967 | 553 | | 263,600 | | | | | CE |
| | Salt Cr[illegible] | Monroe | | 1966 | 441 | | 441,000 | | | | | CE |
| | Wabash [illegible] | Huntington | | 1969 | 707 | | 153,100 | | | | | CE |

(Sheet 6 of 6)

Table D8

Suspended-Sediment Sample Collection Stations - Ohio River Basin

| Subbasin | Stream | Station | River Mile | Period of Record* water yrs | Contributing Drainage Area Above Station** $mi^2$ | Responsible Agency† |
|---|---|---|---|---|---|---|
| Big Sandy-Guyandotte Rivers | Levisa Fork | Paintsville, Ky. | 65.2 | 1961-1973 | 2143 | GS |
| Cumberland River | Cumberland River | Williamsburg, Ky. | | 1954-1962 | 1607 | GS |
| Great Miami River | Great Miami River | Sidney, Ohio | | 1968-1975 | 541 | GS |
| Green River | Barren River | Bowling Green, Ky. | | 1953-1960 | 1848 | GS |
| | Green River | Munfordville, Ky. | 225.9 | 1952 | 1673 | GS |
| Kanawha River | Coal River | Tornado, W. Va. | 11.5 | 1973 | 861 | GS |
| Kentucky-Licking Rivers | Kentucky River | Lock No. 4 at Frankfort, Ky. | 65.9 | 1953-1973 | 5412 | GS |
| | Licking River | McKinneysburg, Ky. | | 1953-1973 | 2326 | GS |
| | | Farmers, Ky. | | 1961-1967 | 831 | GS |

(Continued)

* Water years of complete record inclusive. Years standing alone indicate the beginning of a period of record of a currently operating station.

** Natural flows affected by irrigation development and by storage in an undetermined number of large and small reservoirs.

† GS - U. S. Geological Survey.

Table D8 (Concluded)

| Subbasin | Stream | Station | River Mile | Period of Record* water yrs | Contributing Drainage Area Above Station** $mi^2$ | Responsible Agency† |
|---|---|---|---|---|---|---|
| Lower Ohio River | Salt River | Shepherdsville, Ky. | 22.8 | 1953-1961 | 1197 | GS |
| | Tradewater River | Oleny, Ky. | 72.7 | 1953-1973 | 255 | GS |
| Middle Ohio River | Little Miami River | Near Oldtown, Ohio | | 1953-1958 | 129 | GS |
| | | Near Selma, Ohio | | 1953-1958 | 50.6 | GS |
| | Tygarts Creek | Near Greenup, Ky. | 28.1 | 1957-1973 | 242 | GS |
| Monongahela River | Monongahela River | Braddock, Pa. | 10.0 | 1973-1979 | 7337 | GS |
| Muskingum River | Muskingum River | Dresden, Ohio | | 1953-1974 | 5982 | GS |
| Scioto River | Scioto River | Higby, Ohio | | 1954-1974 | 5129 | GS |
| Wabash River | East Fork White River | Seymour, Ind. | 214.6 | 1967 | 2341 | GS |
| | Eel River | Near Logansport, Ind. | 7.4 | 1970 | 789 | GS |
| | Raccoon Creek | Near Fincastle, Ind. | 48.8 | 1960-1971 | 139 | GS |

Table D9

Maintenance Dredging in the Ohio River Basin*

| | Quantity of Material Dredged from the Ohio River and Tributaries,** $yd^3$ | | | |
|---|---|---|---|---|
| Fiscal Year | Huntington District | Louisville District | Nashville District | Pittsburgh District |
| 1968 | 18,000 | 2,803,000 | 27,000 | 54,000 |
| 1969 | 288,000 | 3,539,000 | 33,000 | NONE |
| 1970 | 25,000 | 3,304,000 | 1,000 | 85,000 |
| 1971 | 391,000 | 2,372,000 | 70,000 | 108,000 |
| 1972 | 211,000 | 2,978,000 | 159,000 | 165,000 |
| 1973 | 677,000 | 3,667,000 | 123,000 | 163,000 |
| 1974 | 746,000 | 2,578,000 | 397,000 | 72,000 |
| 1975 | 479,000 | 1,795,000 | 22,000 | 40,000 |
| 1976 | 521,000 | 1,416,000 | 28,000 | 64,000 |
| 1976-T | 384,000 | NONE | 18,000 | 4,000 |
| 1977 | 823,000 | 988,000 | 280,000 | 124,000 |
| 1978 | 1,128,000 | 1,101,000 | 61,500 | 40,000 |

* File information provided by U. S. Army Engineer Division, Ohio River.

** Huntington and Louisville District figures represent only Ohio River dredging. Nashville data include dredging in the Tennessee and Cumberland Rivers; the Pittsburgh District information includes material taken from the Allegheny, Monongahela, and Ohio Rivers.

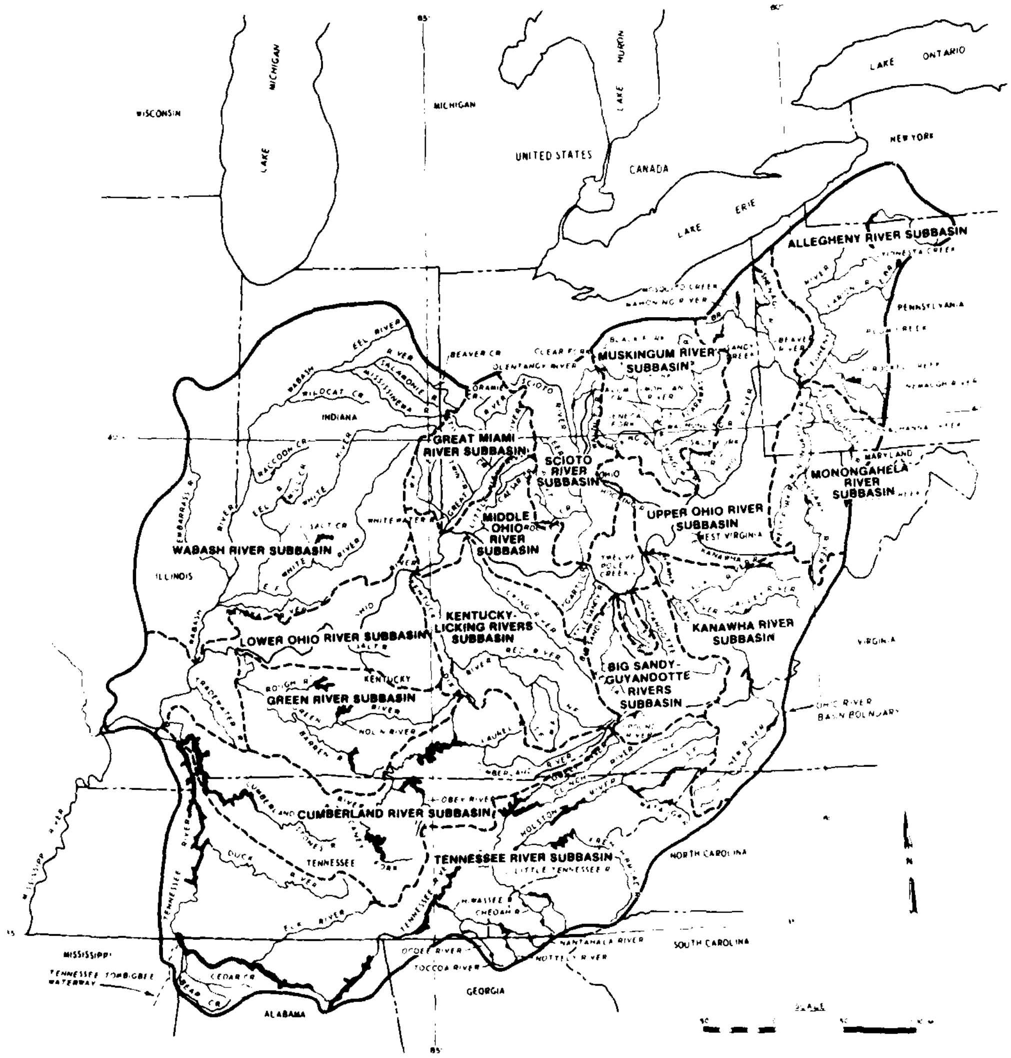


Figure D1. Subbasins of the Ohio River Basin

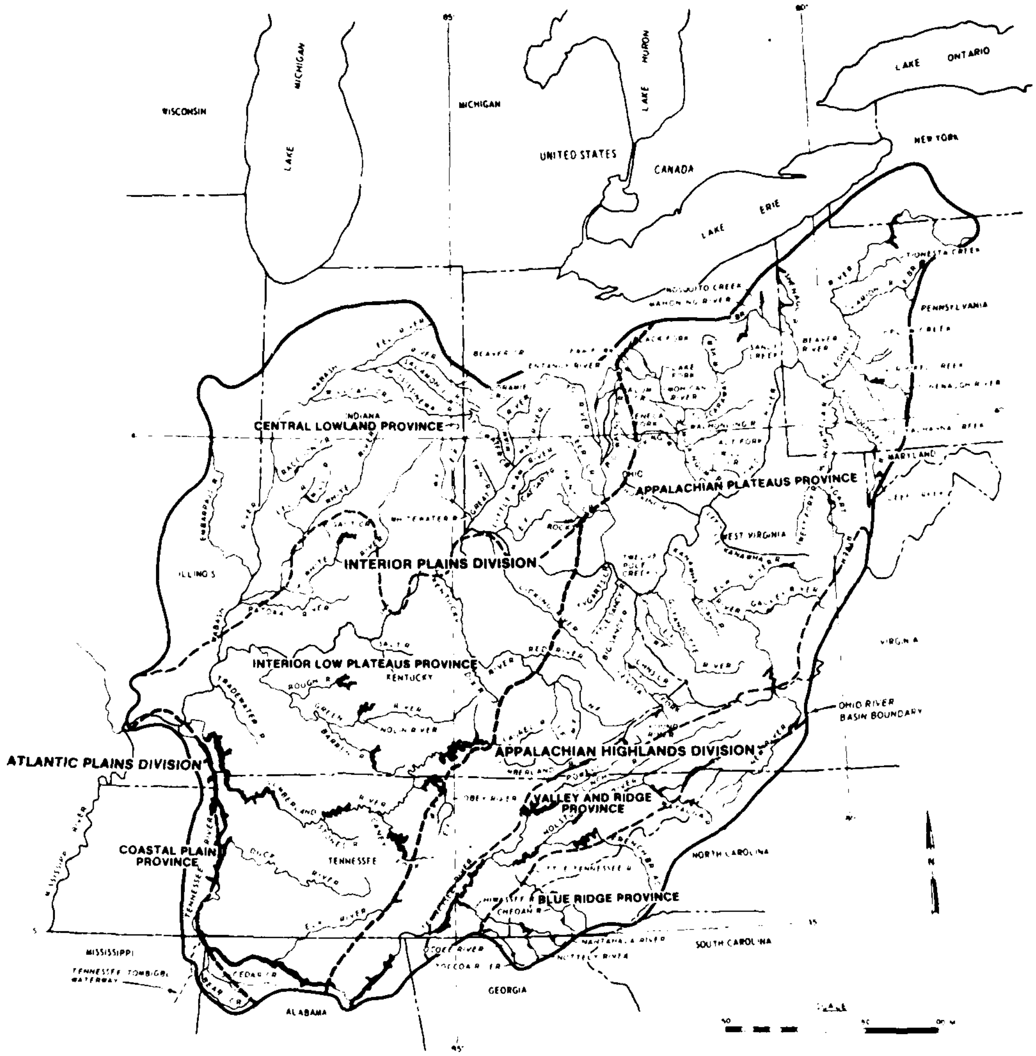


Figure D2. Physiographic map of the Ohio River Basin (Adapted from Reference 3)

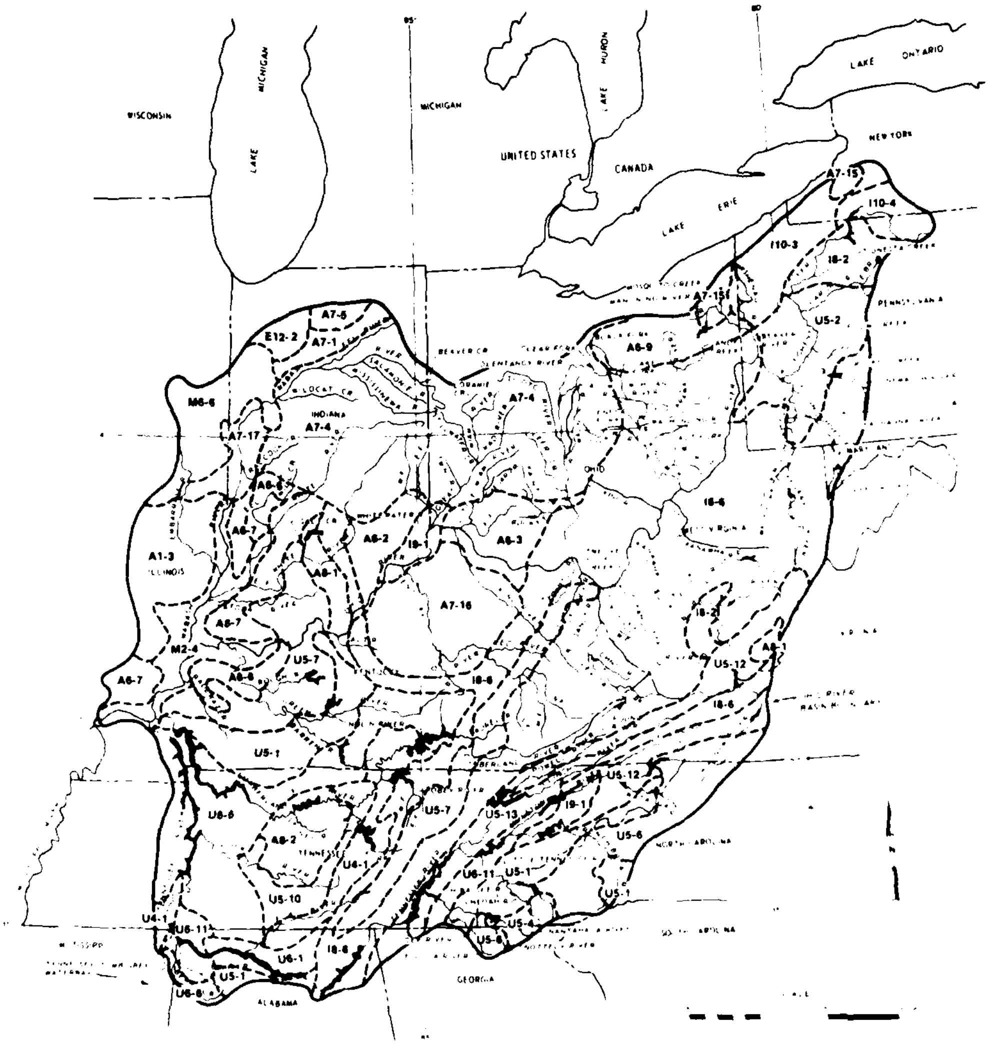


Figure D3. Soils map of the Ohio River Basin (Legend for the soil classifications given in Table 1 of the main text)

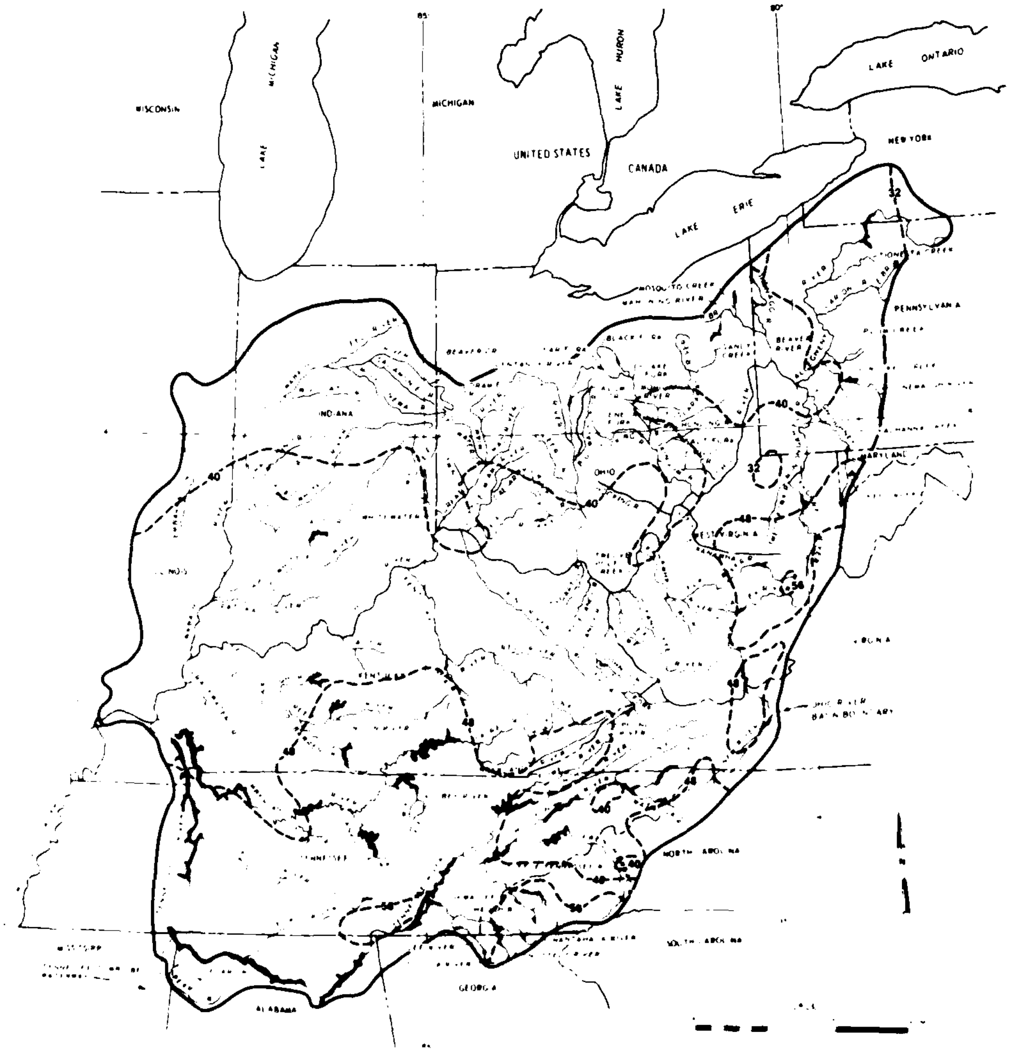

Figure D4. Mean annual total precipitation over the Ohio River Basin (Adapted from Reference 1)

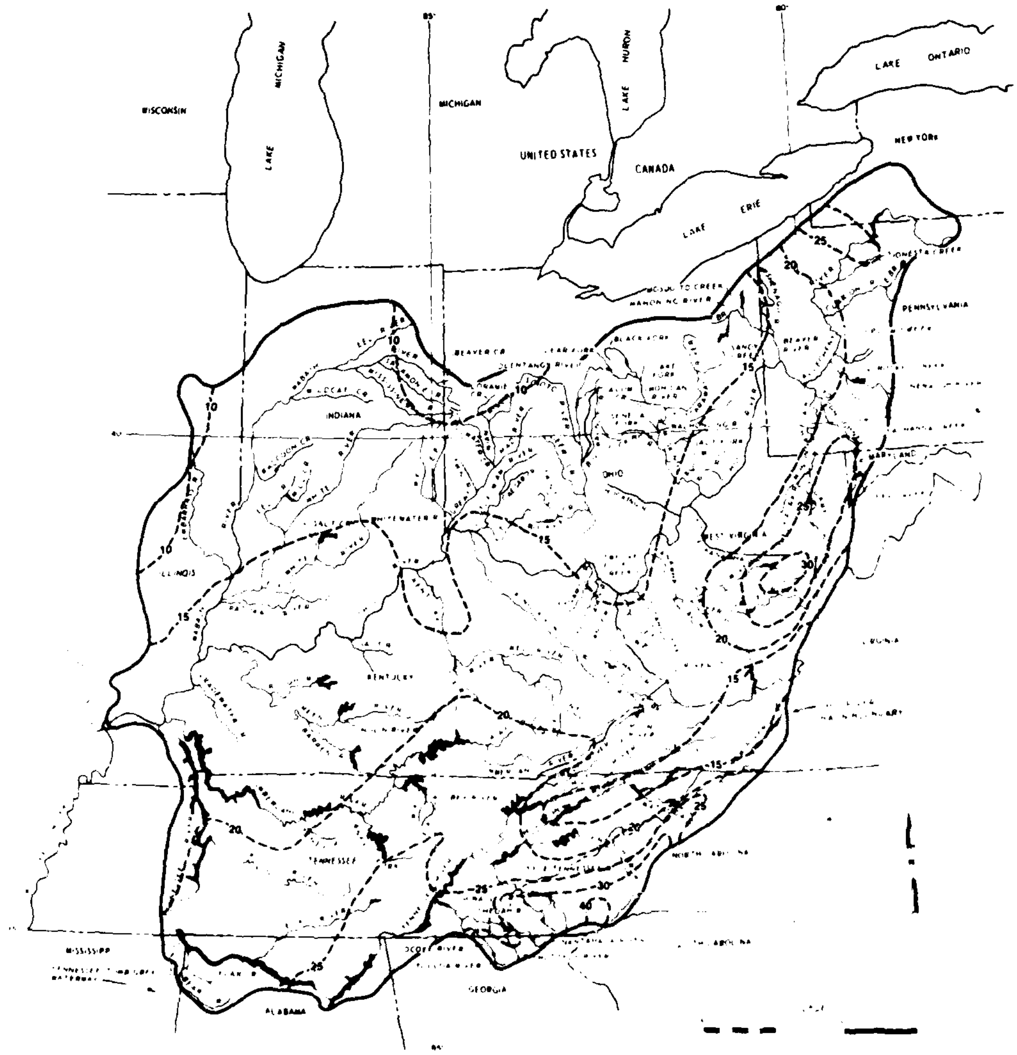

Figure D5. Generalized estimates of mean annual runoff in the Ohio River Basin (Adapted from Reference 1)

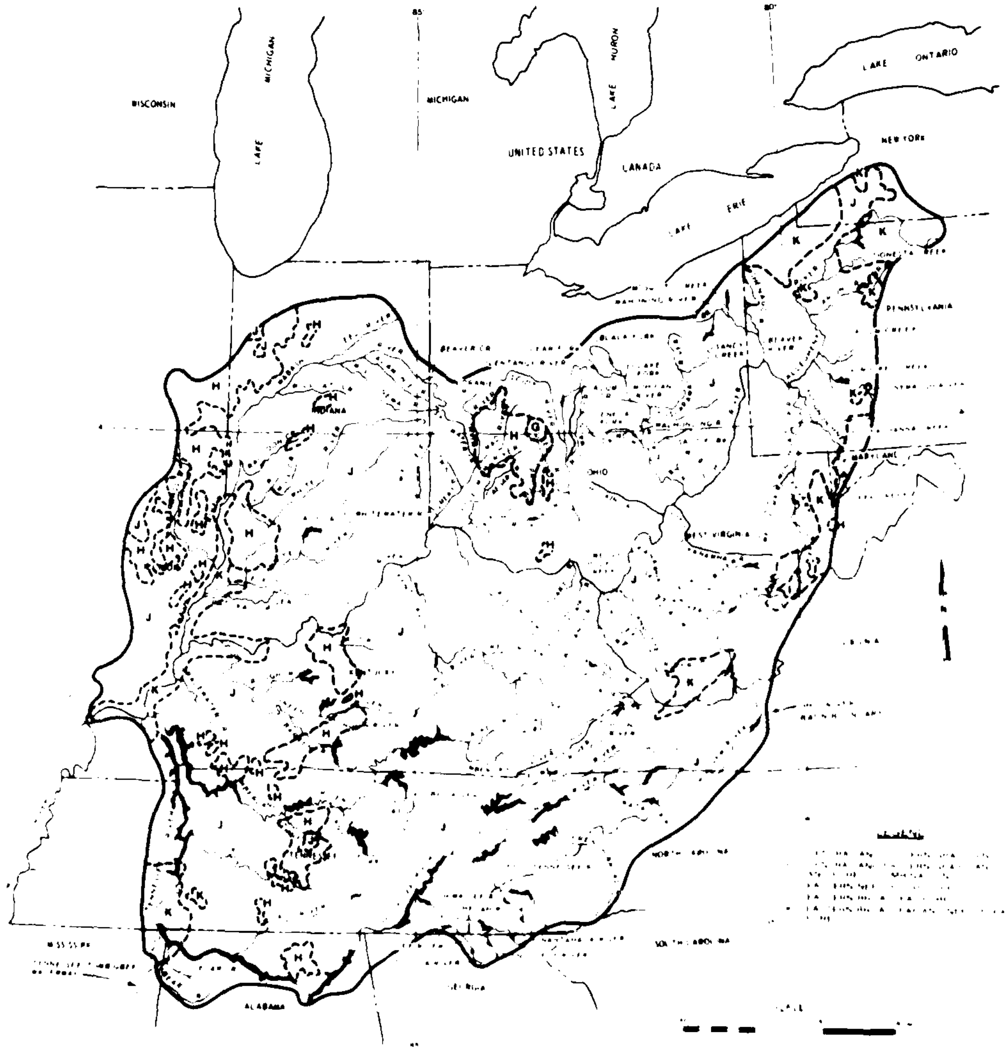


Figure D6. Potential natural vegetation of the Ohio River Basin (Adapted from Reference 4)

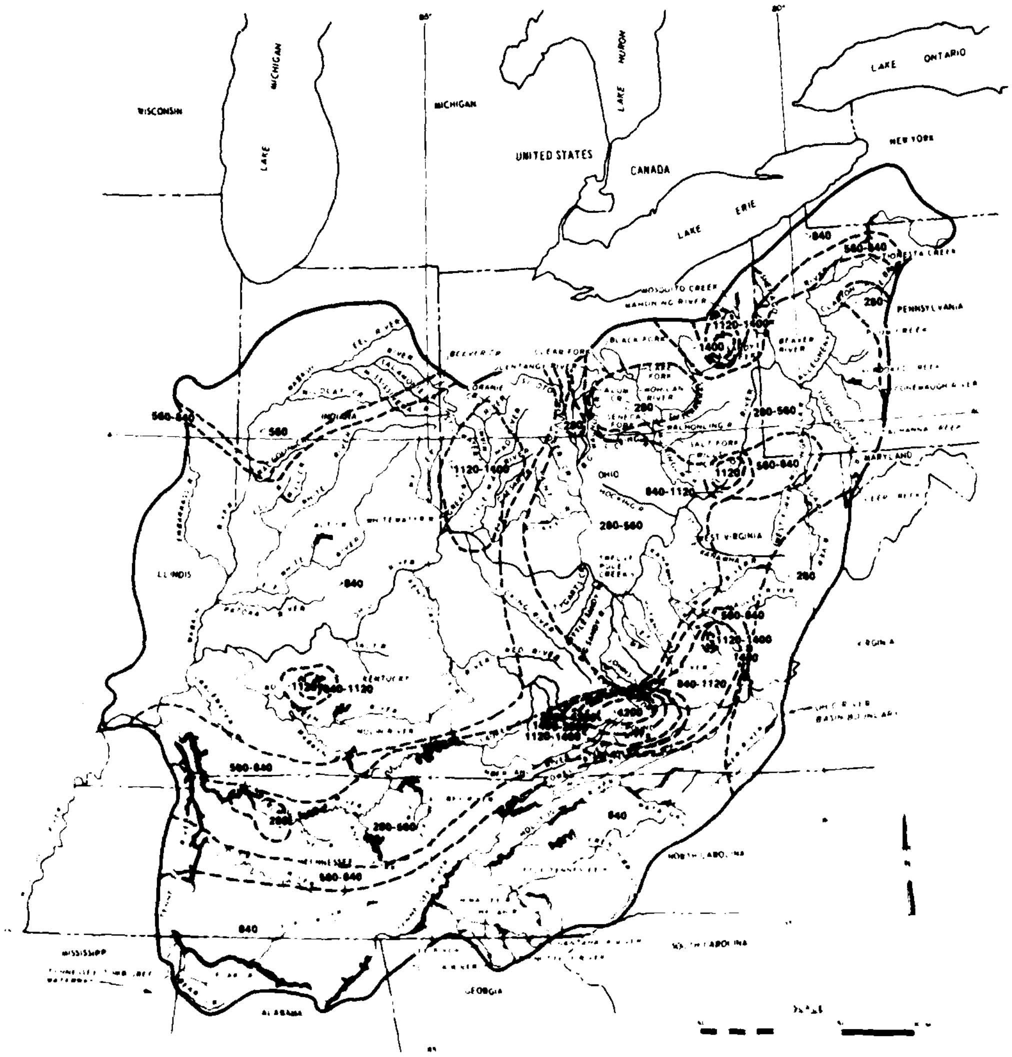


Figure D7. Sediment yield (tons/mi$^2$/yr) for drainage areas in excess of 100 square miles in the Ohio River Basin (Adapted from file information developed from reservoir sediment surveys provided by the U. S. Army Engineer District, Ohio River)

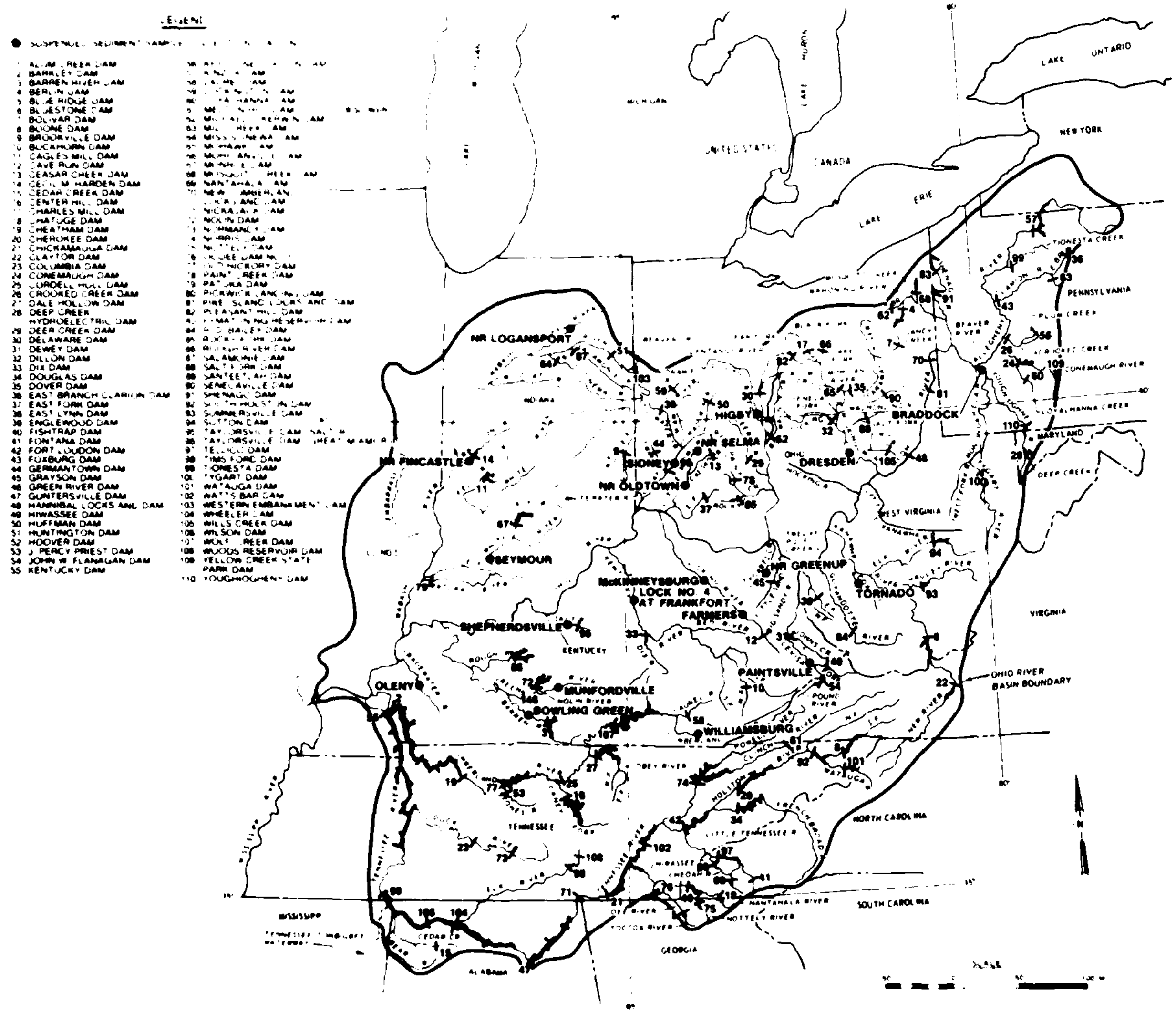


Figure D8. Locations of dams and sediment sample collection stations in the Ohio River Basin

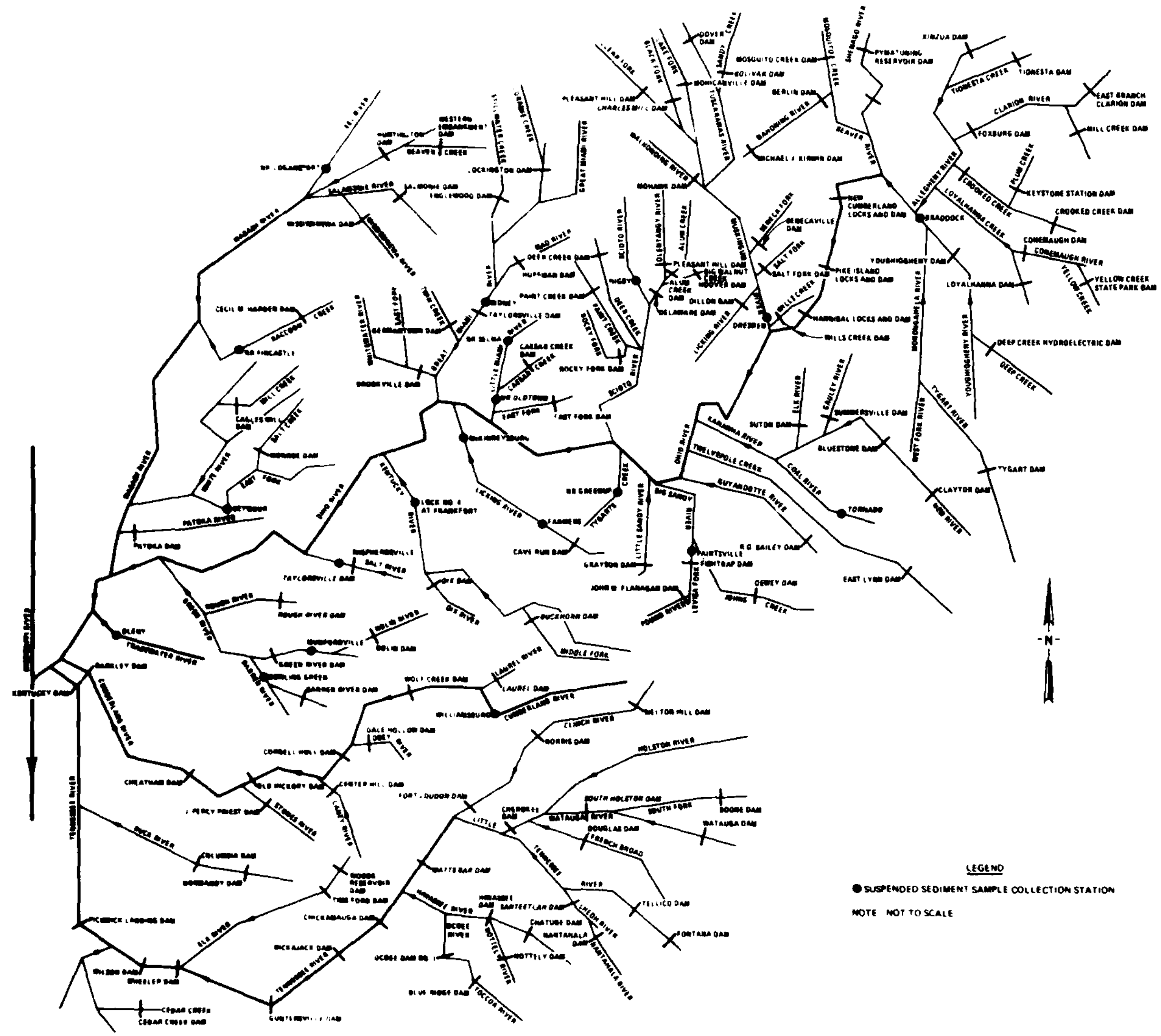


Figure D9. Locations of dams and sediment sample collection stations in the Ohio River Basin shown on linear streamflow diagram

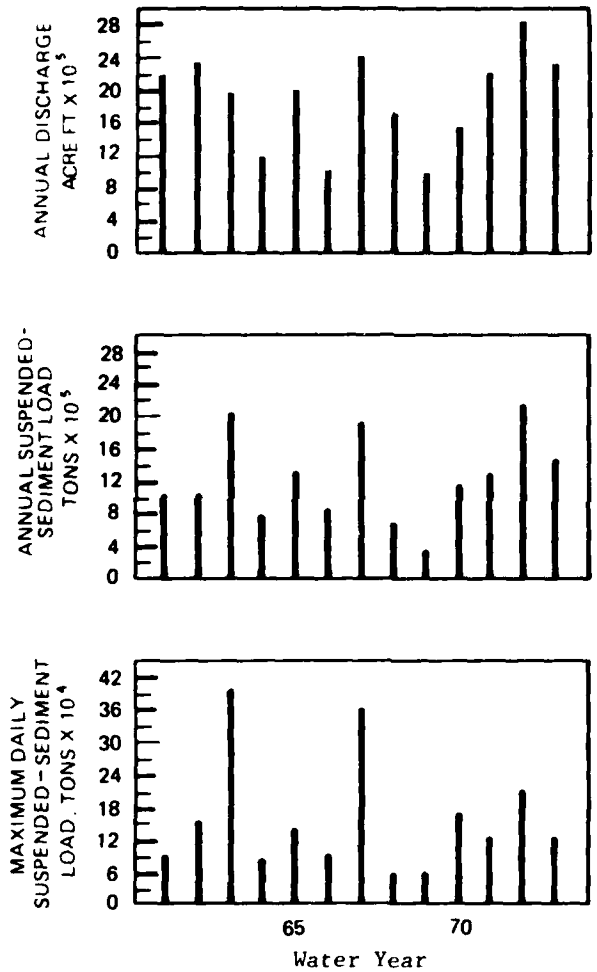


Figure D10. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Levisa Fork at Paintsville, Ky. (Note: Figures D10-D27 are presented by subbasin following the listing in Table D8)

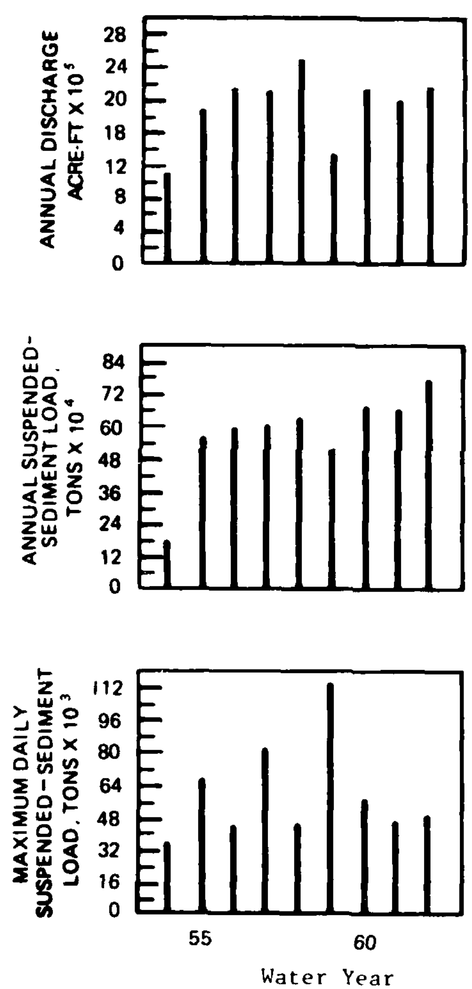


Figure D11. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Cumberland River at Williamsburg, Ky.

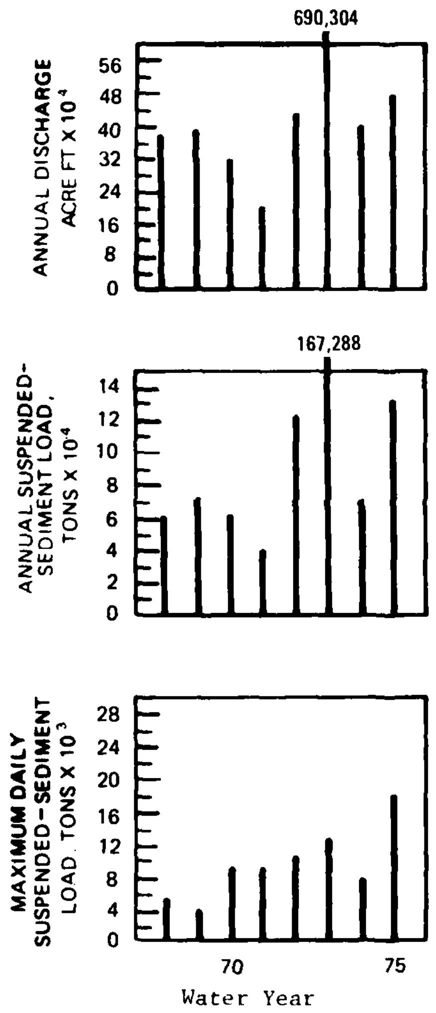


Figure D12. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Great Miami River at Sidney, Ohio

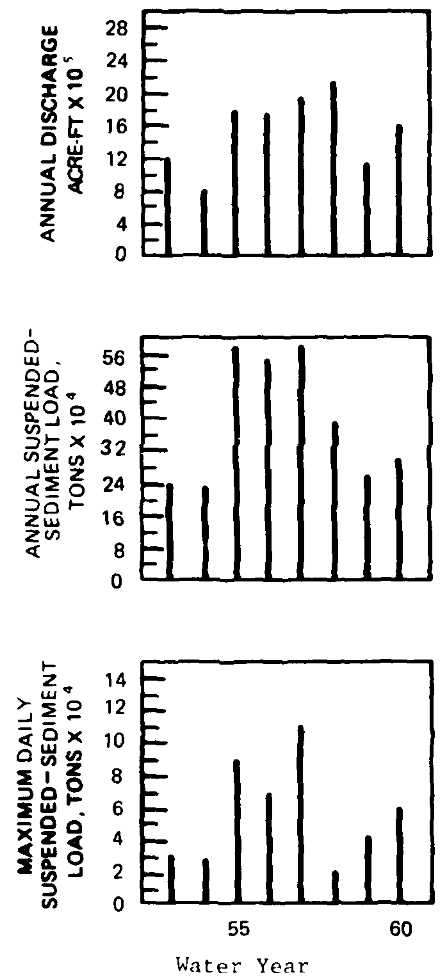


Figure D13. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Barren River at Bowling Green, Ky.

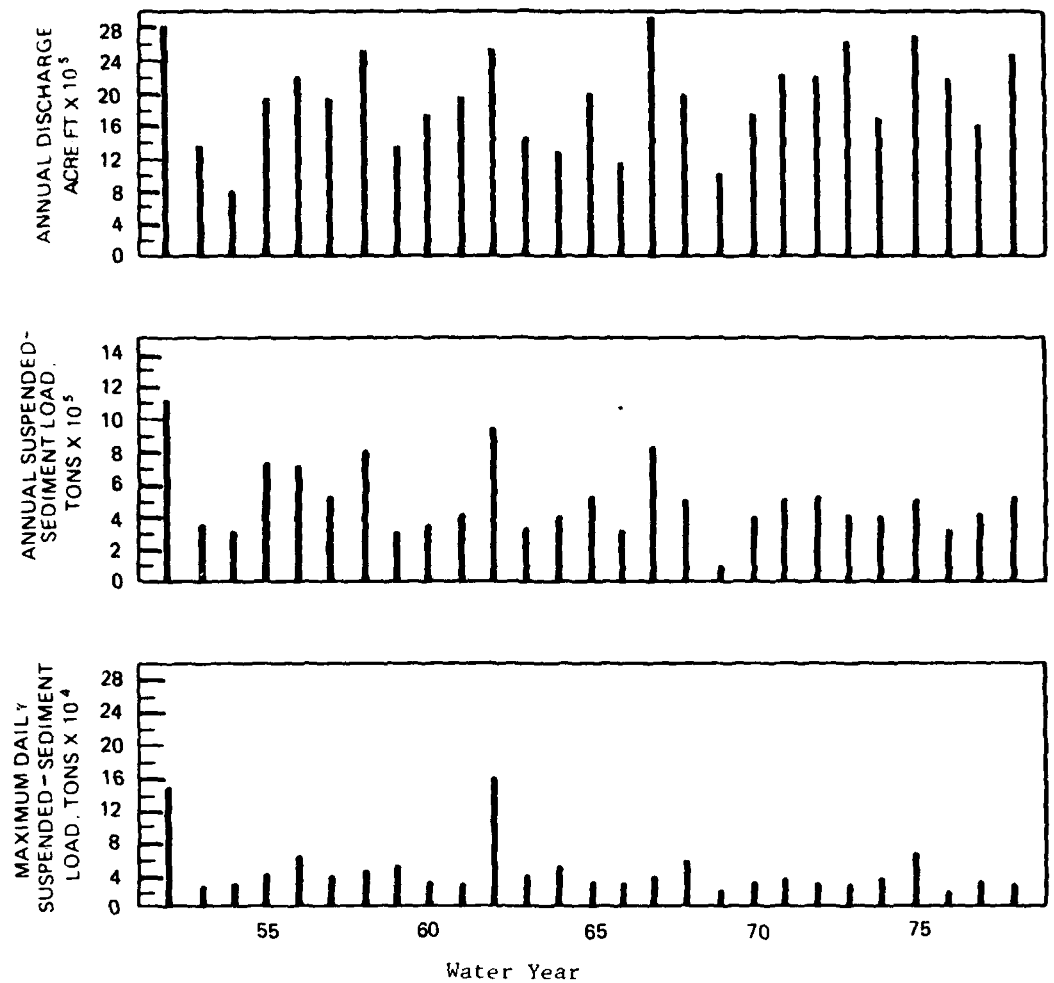


Figure D14. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Green River at Munfordville, Ky.

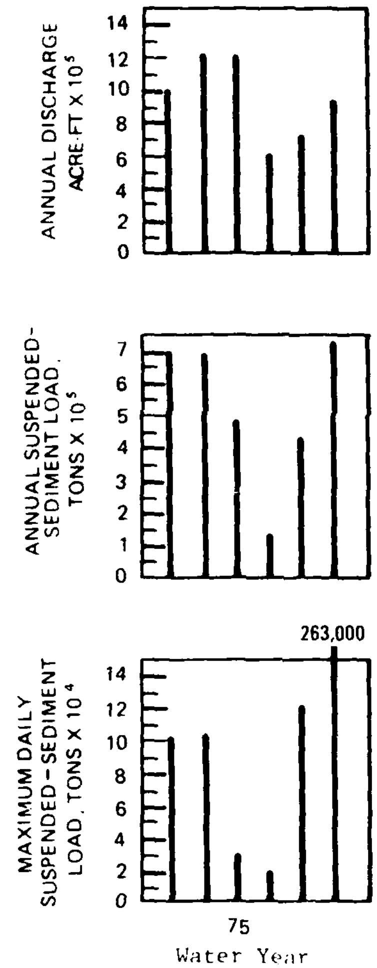


Figure D15. Annual discharge and suspended-sediment load and maximum dailv suspended-sediment load for the station on Coal River at Tornado, W. Va.

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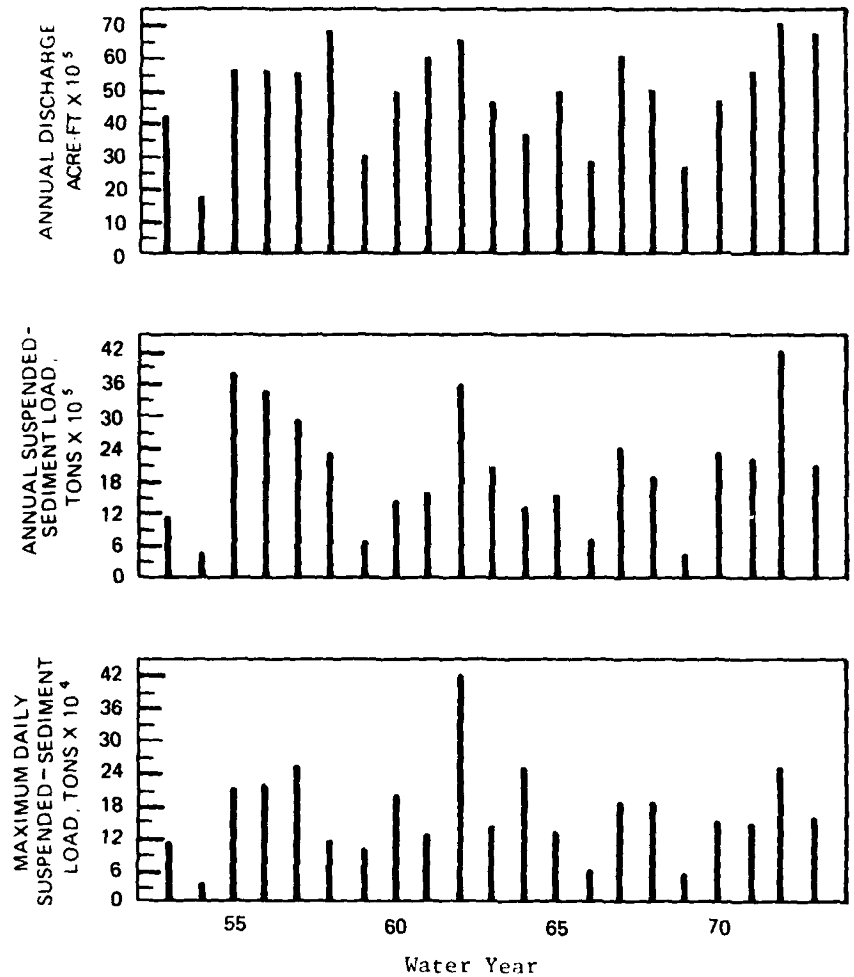


Figure D16. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Kentucky River at Lock No. 4, Frankfort, Ky.

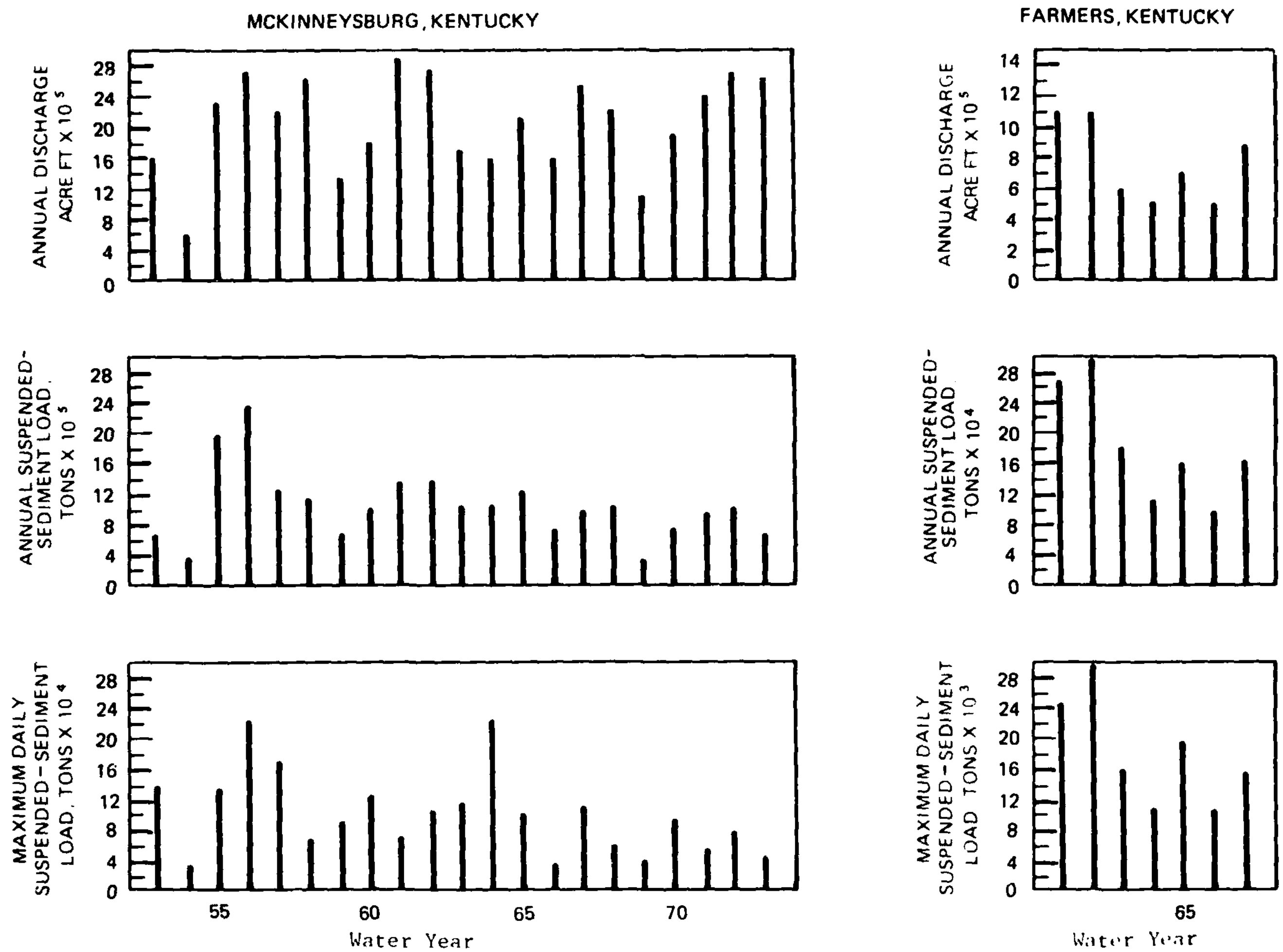


Figure D17. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the stations on Licking River at McKinneysburg, Ky., and Farmers, Ky.

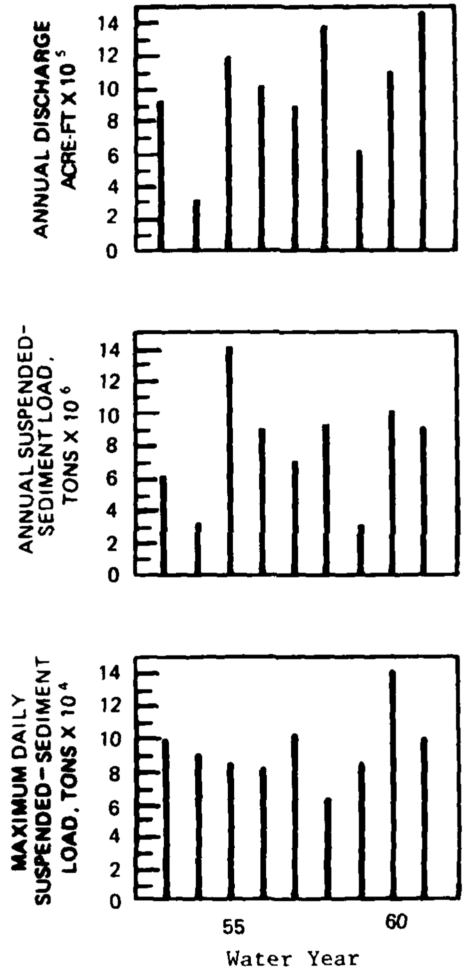


Figure D18. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Salt River at Shepherdsville, Ky.

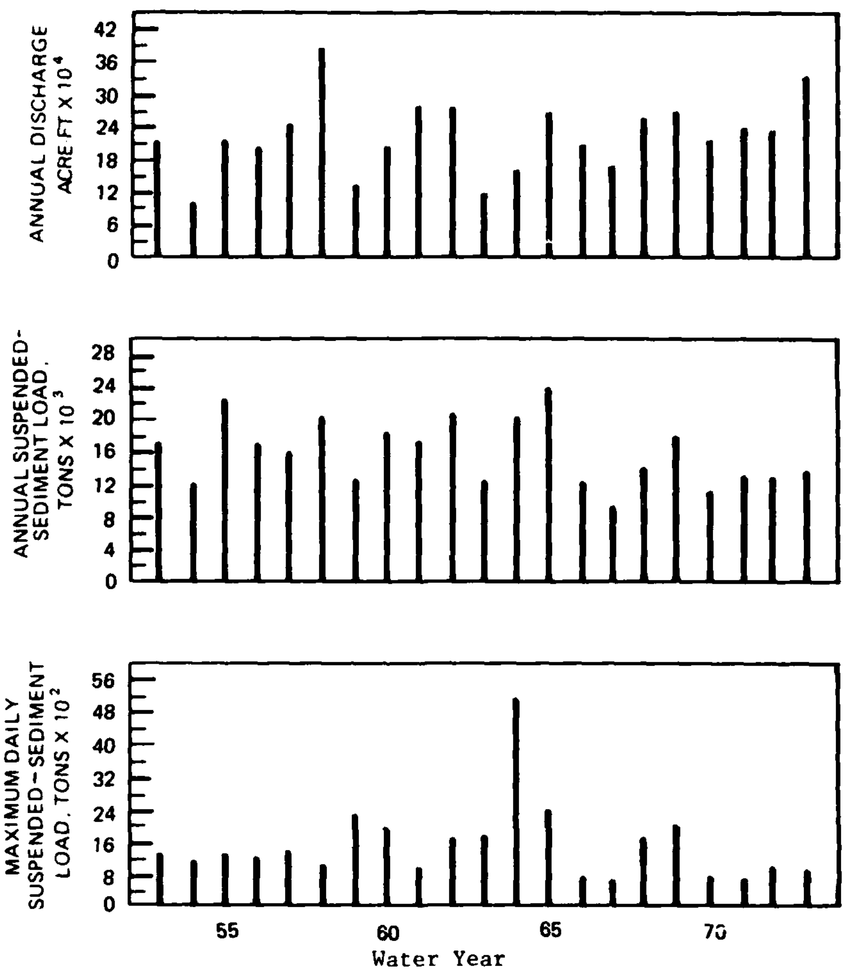


Figure D19. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Tradewater River at Oleny, Ky.

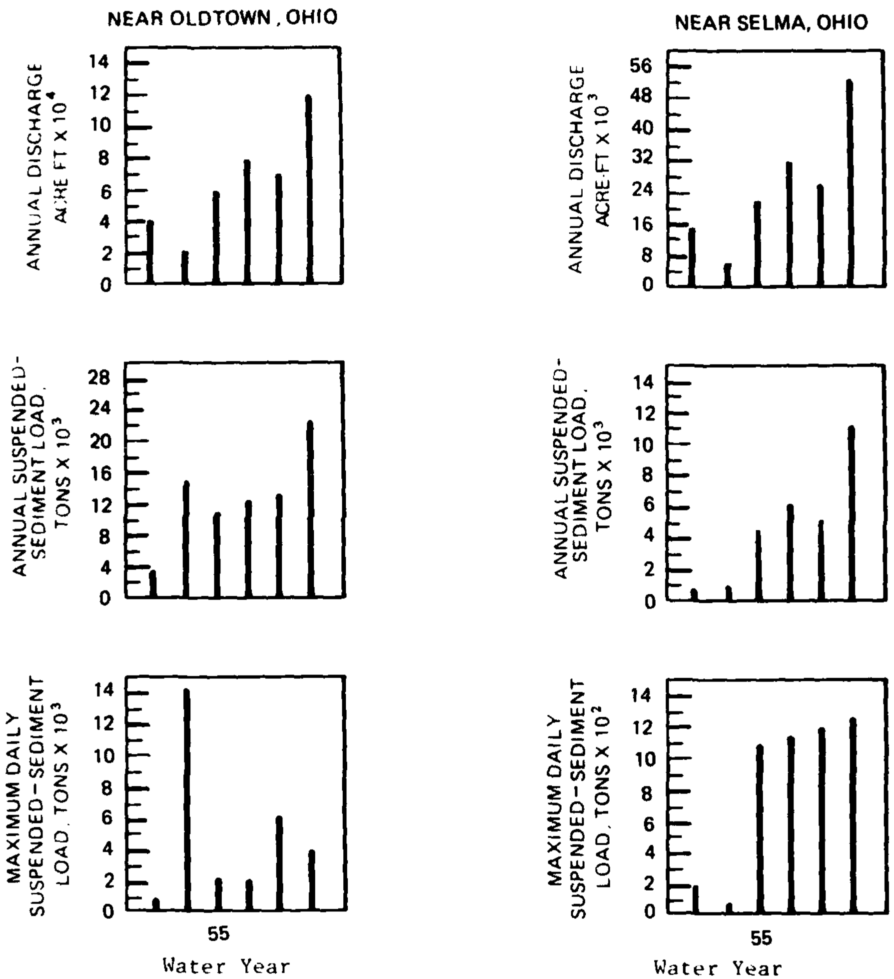


Figure D20. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the stations on Little Miami River near Oldtown, Ohio, and near Selma, Ohio

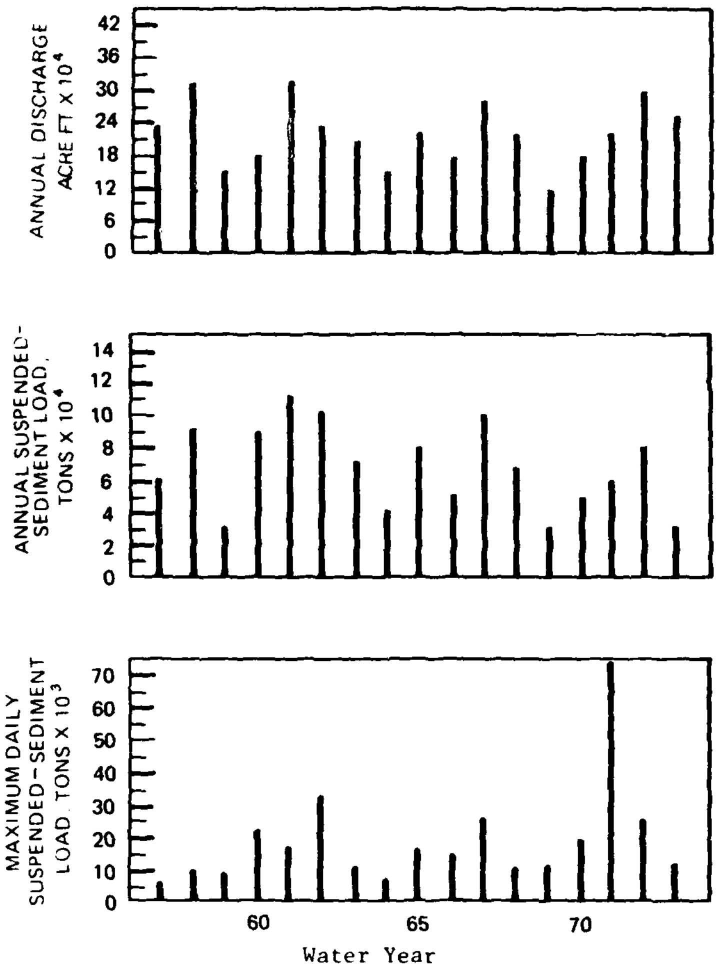


Figure D21. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Tygarts Creek near Greenup, Ky.


Figure D22. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Monongahela River at Braddock, Pa.

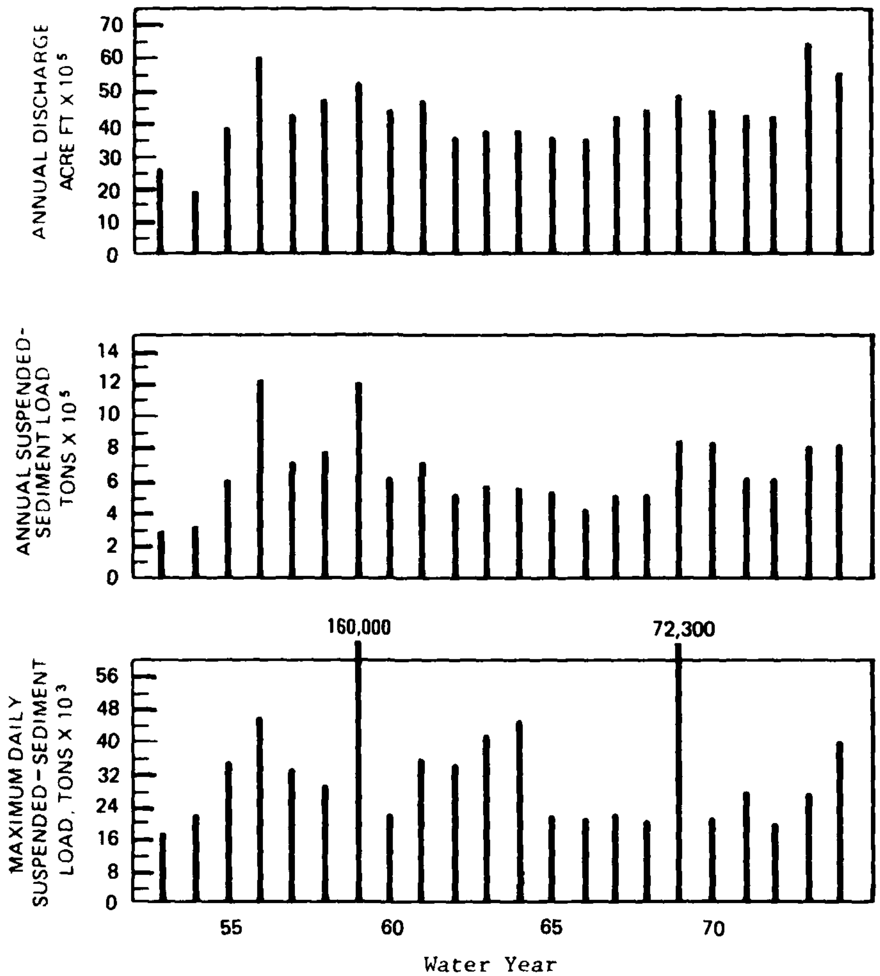


Figure D23. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Muskingum River at Dresden, Ohio

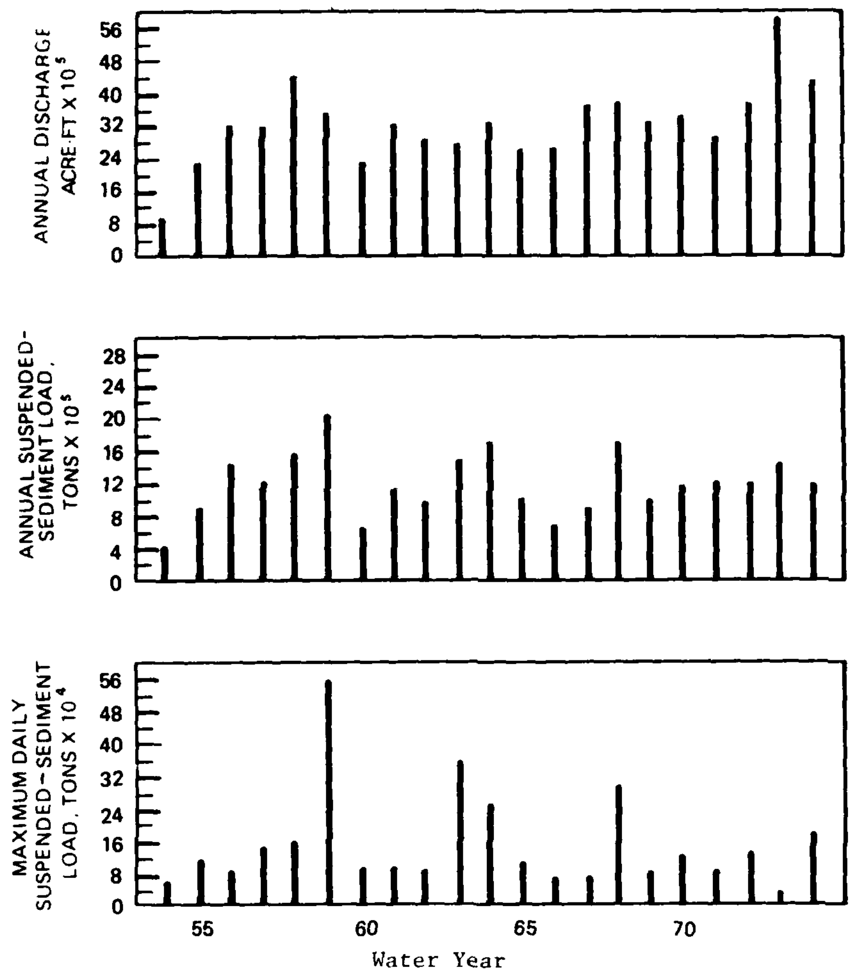


Figure D24. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Scioto River at Higby, Ohio

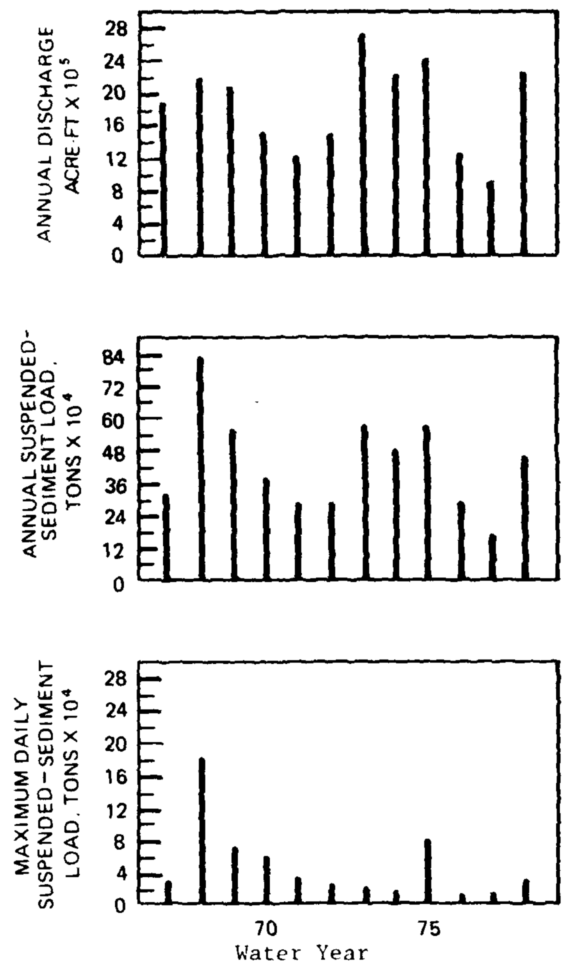


Figure D25. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on East Fork White River at Seymour, Ind.

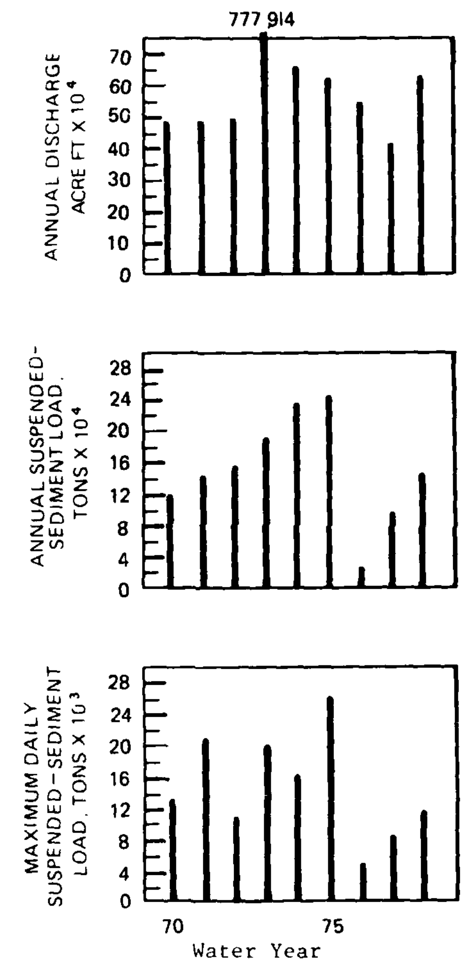


Figure D26. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Eel River near Logansport, Ind.

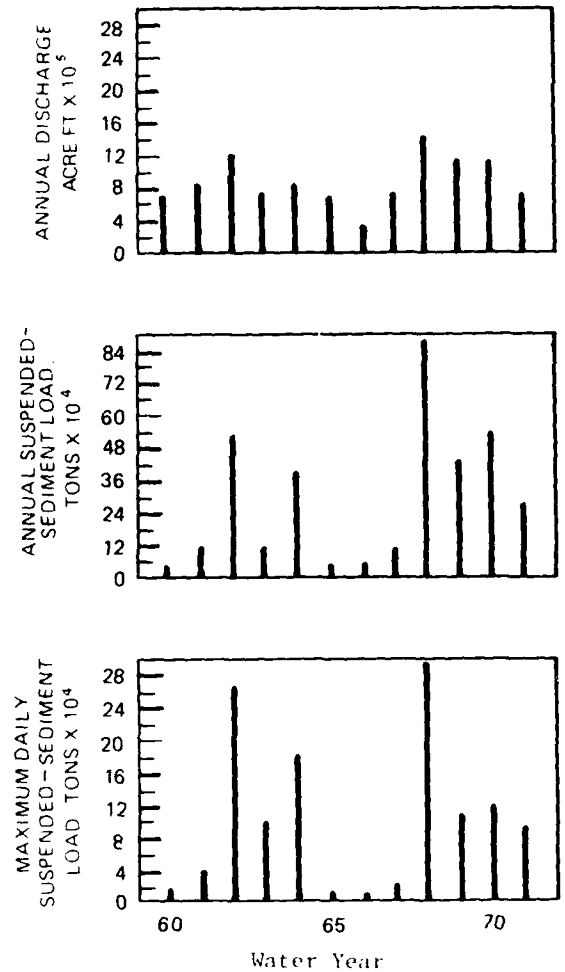


Figure D27. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Raccoon Creek near Fincastle, Ind.

# APPENDIX E: CHARACTERIZATION OF THE SUSPENDED-SEDIMENT REGIME AND BED-MATERIAL GRADATION OF THE ARKANSAS-WHITE-RED RIVERS BASIN

## PART I: ENVIRONMENTAL CHARACTERIZATION

### Introduction

1. Three major streams drain this basin. The Arkansas River carries flow from the central and northern part of the basin (160,851 square miles), emptying into the Mississippi River near mile 581. Discharges from the northeastern corner of the basin (25,000 square miles) are channeled to the Mississippi by the White River, which meets the main stem at mile 599. The Red River drains the southern portion of the basin (96,079 square miles), joining with the Lower Old River in central Louisiana to form the Atchafalaya.

2. The Arkansas River and its major tributaries, the Canadian and Cimarron, have their headwaters in the southern Rocky Mountains of Colorado and New Mexico where elevations range from 8,000 to 10,000 ft with some peaks rising to 14,000 ft.[1*] The streams flow through canyons and gorges in the higher elevations finally emerging onto the adjoining High Plains as meandering rivers. From eastern New Mexico and Colorado the nearly unbroken surface of the plains extends for many miles with elevations gradually diminishing from 5,000 ft to less than 2,500 ft. The Arkansas, Cimarron, and Canadian Rivers flow generally eastward across the High Plains, towards the eastern edge where the plains become more dissected by stream valleys and give way to the Central Lowlands (see paragraph 13). Within the Central Lowlands, well-defined drainage courses become more numerous and streamflows increase notably. In particular, the Verdigris and Grand (Neosho) Rivers contribute large flows to the main stem of the Arkansas River. Farther east, the Arkansas is flanked by the Ozark Plateaus to the north and the Ouachita Mountains to the south. As the Arkansas approaches its confluence with the

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* References are listed in the Reference section at the end of the text of this Appendix.

Mississippi main stem (at an elevation of 145 ft), it meanders through a wide alluvial floodplain in eastern Arkansas with the floodplain being broken only by occasional abandoned channels.

3. The White River rises in the Boston Mountains of Madison County, Ark., and follows a generally northern course until it crosses the Missouri state line into Barry County, Mo.[2] The stream then flows in an easterly direction through southern Missouri for a distance of some 100 miles before turning towards the southeast and continuing towards its confluence with the Mississippi River near historic Arkansas Post.

4. The Red River has its headwaters in the High Plains of the Texas Panhandle and eastern New Mexico. Most streams in this area are subject to intermittent flow, and thus the source of the Red is often difficult to accurately locate at a given time. Downstream from the headwaters area, the Red travels across the Central Lowlands, where it forms the Oklahoma-Texas state line. As the main stem emerges from the Central Lowlands, it passes through the gently rolling Coastal Plain (see paragraph 13) where elevations are generally less than 500 ft. The stream has a nearly flat gradient through this reach, adjoining an alluvial plain 2 to 12 miles wide. Numerous tributaries that rise in the southern Ouachitas and the hilly areas to the west contribute substantially to the flow of the Red River in eastern Oklahoma and western Arkansas. The Ouachita River, the major downstream tributary, rises in the Ouachita Mountains and flows through the hilly uplands of southeastern Arkansas and the alluvial valley of the Mississippi River before entering the Red River just above its mouth.

5. The Arkansas-White-Red Basin is composed of seven well defined subbasins: the Cimarron-North Canadian-Canadian Rivers, the Lower Arkansas River, the Lower Red River, the Ouachita River, the Upper Arkansas River, the Upper Red River, and the White River. A description of these subbasins is provided in the following paragraphs (Table E1 and Figure E1).

6. The Cimarron-North Canadian-Canadian Subbasin drains portions of Colorado, Kansas, New Mexico, Oklahoma, and Texas. The drainage from

this subbasin is passed into the Arkansas River by the Cimarron at Keystone Lake and by the Canadian River at Robert S. Kerr Reservoir. The Cimarron River rises in the Johnson Mesa area of northeastern New Mexico and travels some 700 miles southeastward to its confluence with the Arkansas.[3] The Cimarron generally has a shifting channel with an adjacent wide flat floodplain. The streambed slope in the upper reaches is relatively steep but becomes flatter as the stream progress downstream. The Canadian River has its headwaters in the Sangre de Cristo Range of northeastern New Mexico and flows southward across the Las Vegas Plains, cutting a gorge nearly 1500 ft deep in the escarpment before turning eastward. The stream continues through the Texas Panhandle in a deep, narrow valley cut into reddish sandstones, and then flows eastward through the Antelope Hills of Oklahoma, past Oklahoma City, to join the Arkansas River near the western edge of the Boston Mountains. Through most of its 900-mile course, the Canadian is a braided stream. The principal tributary of the Canadian River, the North Canadian, rises in Union County, N. Mex., where its upper reaches are also known as the Beaver River. The stream then flows 850 miles through the Texas and Oklahoma panhandles to its confluence with the Canadian River at Eufaula Lake.

7. The Lower Arkansas River Subbasin includes all drainage area downstream from Keystone Dam except the region emptied by the Canadian River watershed. The subbasin covers southeastern Kansas, northeastern Oklahoma, southwestern Missouri, and northwestern and central Arkansas. During flood, the Arkansas carries a heavy load of sand and silt, derived largely from the southwestern tributaries, and from materials fed into the stream by caving banks. The average velocity of the water in narrow portions of the channel typically reaches 13 ft/sec during flood, with maximum current velocites in excess of 16 ft/sec often occurring. In the reach between Keystone Dam and the mouth of the Grand (Neosho) River, the average fall of the stream is 2.1 ft/mile, with the differential between low and high river stages being about 20 ft. From the mouth of the Grand (Neosho) River to Little Rock the streambed gradient is 0.9 ft/mile; between Little Rock and the mouth this value decreases to 0.4 ft/mile. The alluvial valley of the Arkansas River in eastern

Oklahoma and western Arkansas varies from 1.5 to 3 miles in average width and is rather well defined by the adjoining hills and mountains. Downstream from Little Rock, the valley merges with the Mississippi alluvial plain. A considerable portion of the valley land adjacent to the main stem in Arkansas, and some areas in Oklahoma, have been leveed. The Arkansas is navigable through mile 397; at this point the navigation channel follows the Verdigris River, which is navigable for 50 more miles to the Port of Catoosa, Okla. (serves Tulsa).

8. The Lower Red River Subbasin includes all drainages to the Red River downstream from Denison Dam (except that of the Ouachita Subbasin), which flow from portions of southeastern Oklahoma, northeastern Texas, southwestern Arkansas, and northwestern Louisiana.[4] The subbasin outline tapers from a width of 130 miles in the upper portion to 20 miles in the lo. r part, and with its length measured along the major axis being 400 miles. The terrain in the tributary areas draining into Red River varies from rugged mountains to low, rolling hills. The elevation of the alluvial land along the main stem of the Red ranges from 35 ft at the mouth to more than 500 ft near Denison Dam. The natural alluvial valley is characterized by a meandering stream course, natural levees, oxbow lakes, and abandoned stream channels. In the past, the Red frequently eroded new channels, cutoff loops, and deposited sediments in overflow areas as it meandered within the floodplain. The settling of coarser materials during floods built natural levees more or less contiguous to the main stem, while deposits of finer particles formed relatively impervious blankets in the slack-water areas. At the present time, a nearly continuous system of man-made levees protects both banks of the Red River from Bowie County, Tex. (northwest of Texarkana) to a point downstream from Alexandria, La. These levees, together with headwater reservoirs on the main stem and tributary streams, afford protection to the fertile valley lands.

9. The Ouachita River (a left-bank tributary of the Red River via the Black River) is the principal stream in the Ouachita River Subbasin, draining an area of 19,995 square miles in southern Arkansas and northeastern Louisiana.[5] The Ouachita heads in the Ouachita Mountains near

the Oklahoma state line and flows about 50 miles eastward through steep terrain into Lake Ouachita. From this reservoir, the river flows southeastward to Lake Hamilton, and then to Lake Catherine. These lakes, both private developments near Hot Springs, Ark., operate in tandem to produce hydroelectric power. About 6 miles downstream from Lake Catherine, the river changes directions abruptly and flows southwesterly 25 miles to Arkadelphia, Ark. From this point, the stream bends gently southward and then flows southwestward through forested bottom lands until it reaches Monroe, La. South of Monroe, the river continues its tortuous course through an alluvial plain towards its confluence with the Black River. The Ouachita is navigable from its mouth to Camden, Ark., a distance of 350 river miles.

10. The Upper Arkansas Subbasin is defined as that drainage of the Arkansas River upstream from Keystone Lake. Through the first 125 miles of flow the Arkansas is a typical mountain stream cascading along a deep channel. The river then flows through a narrow valley flanked by cliffs and foothills to a point where the valley widens into the High Plains near Pueblo, Colo. From the Colorado-Kansas state line to Hutchinson, Kans., the stream is characterized by a broad sandy bed and low banks with insignificant tributary inflow. Owing to the small inflow and to regional climatic characteristics, the river upstream from Hutchinson generally is considered to be a minor flow contributor to the lower reaches. From Hutchinson downstream the tributary inflow significantly increases and the channel deepens. From its source near elevation 14,000 ft the fall of the Arkansas ranges from 110 ft/mile near Leadville, Colo., to 2.2 ft/mile at the lower end of the subbasin.[6]

11. The Upper Red River Subbasin includes 39,734 square miles of drainage upstream from Denison Dam, of which nearly 6,000 square miles is non-contributing. Below its headwaters, the Red crosses the High Plains of the Texas panhandle, and then forms the Oklahoma-Texas state line downstream to Denison Dam. The High Plains area west of the 101st meridian is flat to gently rolling with numerous shallow depressions that have no drainage outlets to streams.[7] The area to the east is a rolling plain with well defined drainage courses.

12. The White River Subbasin drains most of extreme southern Missouri and northeastern Arkansas. The subbasin is fan-shaped, being 250 miles long in a north-south direction and varying in width from 210 miles near the Missouri-Arkansas state line to 50 miles near the mouth of the river.[8] The White River rises in northern Arkansas, flows in a northerly direction to the Missouri-Arkansas state line, and then in a easterly direction for 115 miles in southern Missouri before finally crossing back into Arkansas at river mile 447.5. Downstream from that point, the stream flows in a general southeasterly direction to the mouth of the Black River near Newport, Ark., and then in a southerly direction to join the Mississippi River. The total length of the White River is 720 miles, with the elevation at its source being 2050 ft and the low-water elevation at the mouth 101 ft. The streambed gradient ranges from 25 ft/mile in the headwaters to 0.4 ft/mile near the mouth. The fall of the streambed through most of the Ozark Mountains is 3 to 4 ft/mile. The White River flows through its mountainous reaches in a narrow channel that in numerous places has eroded vertically through rock to a depth of more than 100 ft. The streambed material through these reaches is composed mostly of rocks, boulders, and gravel. From Bull Shoals Dam at mile 418.6 to the head of Beaver Reservoir at mile 685.0, the White River is a series of lakes formed by three dams, Bull Shoals at mile 418.6; Table Rock at mile 528.8; and Beaver at mile 609.0. After it leaves the mountains, the White River is characterized as a meandering stream with flat slopes. The banks and streambed material are composed mostly of fine sand, silt, and clay. In the upstream third of this reach the channel width ranges from 200 to 400 ft between banks whose heights vary from 20 to 25 ft. In the downstream two-thirds of the reach, the channel width ranges from 400 to 800 ft and bank heights vary from 25 to 30 ft. The flow is sluggish in the lower reach because of the flat stream gradient. Oxbow lakes are common along the main channel.

## Physiography and Geology

13. The Arkansas-White-Red Rivers Basin lies in four major

physiographic divisions (Figure E2). The Rocky Mountain System occupies 2 percent of the basin; the Interior Plains 57 percent; the Interior Highlands 18 percent; and the Atlantic Plains 23 percent.[9,10] The major divisions are further divided into provinces as follows:

| Major Division | Province |
|---|---|
| Rocky Mountain System | Southern Rocky Mountain |
| Interior Plains | Great Plains<br>Central Lowlands |
| Interior Highlands | Ozark Plateaus<br>Ouachita |
| Atlantic Plains | Coastal Plain |

14. The Rocky Mountain System Division forms the western boundary of the basin in Colorado and New Mexico. The small part of this division lying in the basin is in the Southern Rocky Mountain Province. This province consists of broad, elevated, north-south strips of Precambrian crystalline rock generally flanked by steeply dipping sedimentary rocks commonly forming foothills.[9] Elevations are between 8,000 and 10,000 ft with some peaks rising above 14,000 ft. Streams flow from their headwaters through canyons and gorges before reaching the adjoining plains as meandering rivers.

15. East of the Rocky Mountain Division is the Interior Plains Division, which covers over half of the basin. The division is divided into the Great Plains and the Central Lowlands Provinces. The eastern boundary of the Great Plains Province lies approximately along the 1500-ft contour, and the western boundary lies at the foot of the Rocky Mountain System at the 5500-ft elevation. From New Mexico and Colorado the nearly unbroken surface of the plains extends eastward for many miles. Elevations gradually diminish to less than 2500 ft at the eastern edge. East of the plains lies a piedmont belt that extends from 50 to 100 miles and includes linear hills and valleys.

16. Towards its eastern boundary the Great Plains Province becomes more dissected by stream valleys and eventually gives way to the Central Lowlands, where elevations decrease from about 1500 ft to between 500

and 1000 ft. The Central Lowlands is a plain of low relief, interrupted at intervals by east-facing escarpments which indicate the presence of stronger strata in a great mass of relatively weak rocks dipping gently west or northwest.[10]

17. The northeastern portion of the Arkansas-White-Red Rivers Basin is covered by the Interior Highlands Division. This division is divided into the Ozark Plateaus and Ouachita Provinces. The Ozark Plateaus lie west of the Mississippi River and south of the Missouri and consists of plateaus that are variously dissected and surrounded by lowlands. The topographical form is that of an asymmetrical dome steeper on the east than on the west and breaking off rather abruptly to the south. In the southern part of the province, Arkansas and Oklahoma, the topography is dominated by the Boston Mountains. In west central Arkansas and eastern Oklahoma and just south of the Ozark Plateaus is the Ouachita Province. This entire area consists either of mountains, intermontane valleys, or piedmont from which the mountains have been carried away by erosion.

18. The southeastern part of the basin lies in the Coastal Plain which is a province of the Atlantic Plain Division. The Coastal Plain is often spoken of as the newer margin of the continent, a relatively recent addition to a growing mass.[10] The province is characterized by low relief and gentle gulfward-sloping Cretaceous rocks. The streams have wide, nearly flat, floodplains; the uplands are irregular and rolling to hilly.

## Soils

19. The locations of the soil types present in the Arkansas-White-Red Rivers Basin are shown in Figure E3 (based on National Coopertive Soil Classification of 1967 compiled by USDA, Soil Conservation Service). The soils covering in the eastern third of the basin (the mountain and coastal plain areas) have developed under mixed coniferous and hardwood forests, making them somewhat acidic, with relatively little organic matter when compared to the grassland soils to the west.[11]

Along the lower reaches of the Arkansas, White, and Red Rivers, the soils have been deposited in relatively recent times and have undergone little or no modification. The dark-colored soils of the Central Lowlands have high humus content and have been leached less than the soils of the humid forested areas to the east. The soils of the Great Plains contain less organic matter than those soils of the Central Lowlands, with very little leaching of the available plant nutrients. In the Rocky Mountain foothills, the soils are of granitic origin and very shallow, if present at all.

## Climatology[4,7,8,12-14]

20. The climate of the Arkansas-White-Red Basin ranges from humid in the east to semiarid in the west, being generally characterized by long hot summers and short cold winters. The eastern part of the basin is influenced primarily by warm, moist air from the Gulf of Mexico. The western half of the basin experiences temperature extremes and moisture deficiencies associated with its midcontinental location. In the winter there are frequent intrusions of cold, dry continental air from the north, and in summer, hot, dry winds blow from interior Mexico.

21. The annual precipitation over the basin averages 56 in. in southeastern Arkansas and eastern Louisiana, decreases rather uniformly westward to about 16 in. in the western Great Plains, then increases to 32 in. in the mountains of Colorado (Figure E4). Storm events lasting several days are characteristic of the southeastern part of the basin. In the Great Plains both monthly and annual rainfall are low, with serious deficiencies in crop-season precipitation often occurring. Localized floods in the central and western portions of the basin result from infrequent but intense rainstorms of short duration.

22. The average January temperatures in that part of the basin drained by the Arkansas River range from near 25°F in the northwest to 45°F in the southeast. July temperatures range from 70°F to 82°F with the growing season in this drainage varying from 150 to 220 days, northwest to southeast. The climate of the White River watershed is

classified as humid and continental. The average January temperature is 40°F, increasing to 80°F for July. The growing season ranges from 199 days in the northern part of the watershed to 244 days in the south. The average January temperature for the Upper and Lower Red River drainage varies from 50 to 30°F, east to west, and in July from 80 to 70°F. The growing season varies from 235 days to 185 days.

23. In the eastern part of the Arkansas-White-Red Rivers Basin wind velocities are generally moderate; however, the area is subject to severe storms, usually in the spring and summer, that are accompanied by heavy rainfall, hail, high winds, and occasional tornadoes. High wind velocities and evaporation rates prevail in the dry climate of the western part of the basin. The prevailing winds are from the south.

## Hydrology

24. Streamflow measurements in the Arkansas-White-Red Basin began in 1858 at Alexandria, La., where the discharge of the Red River was determined on an intermittent basis. Gage heights were recorded on a continuous basis at this station beginning in 1872. The basin stream-gaging station with the longest period of record (1888 to the present) for discharge measurement is on the Arkansas River at Cañon City, Colo. Currently there are 38 active stream-gaging stations on the Arkansas River main stem, 22 on the White River, and 10 on the Red.

### Runoff

25. With the exception of the higher elevations of the Rocky Mountains, the western half of the basin suffers from a moisture deficiency (Figure E5).[1] Runoff in the eastern half of the basin is much greater than in the west. The Arkansas River discharge increases from an average annual flow of 263,700 acre-ft near Great Bend, Kans., to 30 million acre-ft near Little Rock; the Red River increases from an average annual flow of 2 million acre-ft at Gainesville, Tex., to 18 million acre-ft near Shreveport, La.; the White River has an average annual flow of about 22 million acre-ft at Clarendon, Ark.

26. The rate of runoff over the basin varies greatly during the

year, being high during the winter and spring months and low in summer and fall. Above-average runoff takes place predominantly in the five-month period January through May, and below normal during the four-month period July through October. The annual runoff over the Arkansas River drainage averages about 3 in. at Cañon City, then drops to only a fraction of an inch in the central semiarid areas of the drainage, increasing to 20 in. or more in some parts of Arkansas. The runoff in the White River watershed averages 16 in./yr. In the Red River valley the annual runoff varies from a fraction of an inch in west to in excess of 20 in. in Louisiana.

Groundwater

27. Groundwater supply over the Arkansas River drainage varies widely in availability and quality from the Kansas-Oklahoma state line to Little Rock. In the area adjacent to the Arkansas main stem, moderately large supplies of groundwater are generally obtainable but only from the alluvium.[3] The quality of groundwater along the Arkansas in much of Oklahoma is unsatisfactory for municipal use; however, downstream from the Arkansas-Oklahoma state line it is suitable for most purposes. Along the Cimarron River the water in the alluvium is mineralized, but terrace deposits along the northern Cimarron River valley supply some water for municipal and industrial use. The Canadian River in the Texas Panhandle and the North Canadian River in the Oklahoma Panhandle flow across the Great Plains, which is underlain principally by the Ogallala Formation. This aquifer provides high groundwater yields for municipal, industrial, and irrigation uses. The original reserve of the portion of the Ogallala Formation lying in the Arkansas-White-Red Basin was estimated to be 460 million acre-ft. Groundwater withdrawals in 1934 were 92,000 acre-ft per year; however, by 1976, annual withdrawals had accelerated to 4,600,000 acre-ft. The current recharge rate is only 69,000 acre-ft, resulting mainly from precipitation. Because the economic future of the Great Plains is heavily dependent upon the capacity of this aquifer to sustain withdrawals, the USGS initiated a study in 1978 to evaluate the response of the aquifer to groundwater management techniques. In the sand bed areas east of the plains, moderately

large supplies are available from the alluvium and a few bedrock aquifers, however the quality of much of the groundwater in this area is poor.

28. Surface water is generally more accessible than groundwater in the upper White River watershed,[8] but in the lower reaches ample groundwater is available. The groundwater quality is satisfactory over the watershed for most purposes, except in certain areas where the water has excessive hardness.

29. The large groundwater reservoir in the upper Red River drainage supplies current municipal, industrial, and irrigation needs; however, the rate of recharge is insufficient to supply future needs indefinitely (paragraph 27). Between the High Plains and Lake Texoma moderate supplies of groundwater are available from the alluvium, from patches of terrace deposits, and in a few places from bedrock aquifers. Downstream from Denison Dam there is an abundant supply of groundwater.[4] The greatest potential for groundwater development is the alluvial deposits that underlie the floodplain of the Red. Wells drilled into these deposits have yielded as much as 500 gpm in Texas and Oklahoma, 1000 gpm in Arkansas, and 1700 gpm in Louisiana. Groundwater from nearly all of these sources is of good quality and generally is suitable for municipal or industrial use with little or no treatment.

Flooding

30. Flood flows in the upper Arkansas main stem are usually sharp-crested and are soon lost in river channel storage and infiltration. The tributary streams west of the 98th meridian have similar characteristics in that, throughout most of their length, extended low flow periods occur with floods, accounting for a large part of their annual discharge.[1] These irregular flow characteristics are less pronounced in the eastern tributary streams. The largest streamflows in the Rocky Mountain headwaters usually result from melting snows in the spring of the year; however, this is not a contributing factor in producing floods in the lower river. Flows from Colorado decrease through western Kansas, where there is practically no inflow. Floods in the main stem from Hutchinson, Kans., to the mouth of the Salt Fork of the Arkansas River

originate in the Kansas area east of the 98th meridian; these flows are occasionally joined by those from the Salt Fork of the Arkansas and Cimarron Rivers to produce major floods to the mouth of the Verdigris River. Because the general storm path over the Arkansas watershed upstream from Tulsa is not in the direction of streamflow, much of the runoff from the Cimarron River generally precedes flows from upstream areas.

31. Major floods in the lower Arkansas River originate from storms occurring in the eastern portion of the drainage, which includes flow from the Verdigris, Grand (Neosho), Illinois, lower Canadian, Poteau, Petit Jean, and Fourche La Fave watersheds, with occasional contribution from the streams above Tulsa. The Grand (Neosho) River is one of the major sources of flood flow in the lower valley, although it drains only about eight percent of the total area of the Arkansas River watershed. The large flood-producing storms occur most frequently during the spring months; however, a study of these events indicates that great storms may occur at any time during the year. The current (1979) flood control measures that have been implemented by the CE in the Arkansas watershed have prevented accumulated damages in excess of one hundred million dollars.

32. Flooding in the White River watershed results from both short intense storms and extended periods of heavy precipitation.[8] In the Ozark Plateaus Province (paragraph 17), the steep slopes of the tributary streams cause rapid concentration of storm runoff and early peaks. In this area intense storms of short duration cause the most severe flooding. Flood peaks in the Coastal Plain Province (paragraph 18) generally result from storm events of longer duration or series of storms over major portions of the basin. The runoff from these storms reaches the Coastal Plain rapidly and the sudden flow results in general flooding. The crests move slowly through the Coastal Plain because of its large amount of overbank storage and extended periods of damaging stages are experienced. The volume of runoff that reaches the Coastal Plain within two to four days is the principal determining factor for peak flows in this area whereas synchronization of flows is the determining factor in the Ozarks. In both the Ozark Plateaus and Coastal

Plain, flooding of the lower bottom areas is probable several times a year. Floods occur most often during the months of March through May; however, large floods have been known to occur in every month of the year.

33. Even with flood control protection projects functioning, losses in the White River Basin are often large and have a significant effect on the economy of the basin.[8] The average annual flood losses as of 1968 amounted to $35,622,900 of which $6,245,800 and $29,377,100 were in the Ozark Plateaus and Coastal Plain areas, respectively. The flood control measures that have been implemented by the Corps of Engineers (CE) in this basin have currently (1979) prevented accumulated damages in excess of $97,000,000. The largest damage centers are located along the Black River, downstream from Poplar Bluff, Mo., to its mouth and along the lower White River and its alluvial tributaries from near the mouth of the Black River to the mouth of the White River. Most of the remaining flood losses are fairly evenly distributed throughout the basin. Urban flood losses amount to only about one percent of the total losses.

34. The Red River drainage is in a region of relatively heavy rainfall. The headwaters of the major tributaries in Oklahoma and Arkansas are in mountainous or hilly terrain. Uncontrolled runoff from these tributary headwater areas often causes severe flooding along the remaining unleveed reaches of the main stem and the lower reaches of the tributary streams. Two of the greatest floods of record in the basin were those of 1938 and 1945. Each had different characteristics as to origin and effect. The 1938 flood flow was derived primarily from heavy runoff in the upper part of the watershed and produced a record peak discharge of 338,000 cfs on the Red at Fulton, Ark. The 1945 flood resulted from heavy runoff from nearly all of the watershed and produced a record peak discharge of 233,000 cfs at Alexandria, La. Other major floods have occurred on the Red River at least once in each decade since 1900. Floods on the tributaries of the Red occur at frequent intervals that generally coincide with floods on the main stem; however, intense local storms can produce flood conditions on a single tributary. The

flood control measures implemented by the CE in this basin have currently (1979) prevented accumulated damages in excess of $40,000,000.

Streamflow and water supply

35. The natural streamflow in the western portion of the Arkansas-White-Red Basin results from snowmelt in the high mountains, rainfall, and return discharge from irrigated land. This natural flow is supplemented by eight transmountain diversions, including the recently completed Charles H. Boustead Tunnel. The average flow in 1962-1971 for the other seven diversions was 71,370 acre-ft per year. The Boustead Tunnel, which began diversion in 1972, is expected to bring an average of 69,200 acre-ft per year to the basin. The natural and supplemented streamflow supply provides most of the water for the irrigated land in Colorado and New Mexico, and is the source of water for about one-third of the municipal systems. In New Mexico and in the upper reaches of the Arkansas River in Colorado the quality of water is satisfactory for both irrigation and domestic purposes. Downstream in Colorado, the mineral content of the Arkansas increases until, at the Colorado-Kansas state line, the surface water becomes unsatisfactory for domestic purposes and only of fair quality for irrigation.[3]

36. Opportunities for the development of additional surface water supplies in the western part of the basin are limited by the flow characteristics of the streams, by mineralization from natural sources, and by pollution from municipal and industrial effluent, including oilfield wastes. The protracted periods of severe drought in the 1930's and the early 1950's have emphasized the need for conservation and prudent use of water throughout the western basin. East of the 98th meridian the development of facilities for supplying the future water requirements of municipalities and industrial establishments is the principal concern; development of water supplies for agricultural uses is of secondary importance since normal rainfall is generally sufficient for the moisture requirements of the principal crops. West of the 98th meridian there are both present and prospective deficiencies in municipal and industrial water supplies, and the need for irrigation supply becomes progressively more important from east to west.

## Vegetation

37. Prior to the radical land-use changes of the past 150 years, the eastern third of the Arkansas-White-Red Rivers Basin and the Rocky Mountains (and adjacent foothills) were forested. The remainder of the basin was principally grasslands. According to Küchler,[15] the natural vegetation of the basin was distributed areally (Figure E6) as follows:

| Map Unit | Vegetation Type | Percentage of Area Covered |
|---|---|---|
| A | Western needleleaf forests | 4.7 |
| B | Western grasslands | 0.5 |
| G | Central and eastern grasslands | 38.4 |
| H | Central and eastern grassland and forest combinations | 21.6 |
| J | Eastern broadleaf forests | 11.3 |
| K | Eastern broadleaf and needleleaf forests | 23.5 |

Current land-use inventories (1967) indicate that approximately 27 percent of the basin area is now used for cropland, 39 percent for pastures and ranges, 23 percent in forests, with the remainder being used for urban areas, lakes, airports, etc. (see paragraphs 80-83).

## PART II: CULTURAL HISTORY

38. The action of natural forces alone, even without the influence of cultural activities, have had sufficient impact to make some of the streams in the Arkansas-White-Red Rivers Basin heavy sediment carriers. Settlement and the resulting changes in land use have accelerated the erosive processes, thus significantly affecting the suspended-sediment regime and bed-material gradation of the basin. In the following paragraphs, a brief history of exploration and settlement, the development of economic and social trends, and an examination of land-use changes are presented. Emphasis is given to those cultural activities that have had the greatest impacts on the suspended-sediment regime and the bed-material gradation.

### Exploration and Settlement

39. The Arkansas-White-Red Rivers Basin has been occupied by man for thousands of years. Historic records do not accurately indicate when the first human inhabitants arrived; however, archeologic evidence strongly suggests that it was probably over 10,000 years ago. European explorers visited the basin beginning in the 1500's. Spanish settlement began west of the basin in 1608 with the founding of Santa Fe. In the eastern and southern basin, French military posts and later settlements were built following the founding of the first permanent settlement at Arkansas Post in 1686. The central and western basin areas did not attract significant numbers of settlers, however, until the United States acquired title over Texas and the Southwest after the Mexican War.

#### Indians[16-19]

40. The first Indians probably arrived in the basin 10,000 years ago or more. These early settlers were nomadic peoples, leaving only scattered artifacts as evidence of their primitive cultures. Agricultural societies developed around 2000 years ago; however, the lives of these Indians were revolutionized with the introduction of the horse in the mid-1700's. In many cases whole tribes almost totally abandoned their agricultural pursuits.

41. Because of the varied environmental conditions in the basin, different lifestyles and cultures were established to adapt to these conditions and to exploit the locally available basin resources in the best possible manner. By the time the Europeans arrived, many distinct tribes were present in the basin including the Arapaho, Cheyenne, and Apache in the western part, and the Pawnee, Kiowa, Wichita, Comanche, and others in the central basin. The Osage, Natchitoches, Quapaw, Illinois, Cadodaquios, Toinica, Taensas, Natchez, and a number of other tribes lived in the eastern and southern parts of the basin. There was some migration after the arrival of the Europeans. The Apaches, who occupied the western short-grass country, were pushed southward and westward by the Comanche, Kiowa, Cheyenne, and Arapaho.

Spanish explorers[18-22]

42. The first Europeans to visit the Arkansas River were those in the exploration party led by Don Francisco Vasquez de Coronado, who crossed the river in what is now western Kansas on 29 Jan 1541. In early summer 1539, Hernando De Soto and his entourage arrived in Florida and began a three-year trek that took them north into the Ohio River Basin and westward towards the Arkansas-White-Red Basin. De Soto travelled from the Mississippi River across the White River and northwestward through the Ozarks into what is now Oklahoma. He crossed the Arkansas River in 1542 near the present site of Fort Smith, and then paralled this watercourse as far downstream as present-day Pine Bluff, Ark. De Soto recrossed the Arkansas and followed the left bank of the stream to its confluence with the Mississippi River.

43. In 1601 Don Juan de Oñate renewed Spanish efforts to locate the reputed gold of the basin. Oñate followed the Canadian River downstream to its confluence with the Arkansas. Like Coronado and De Soto, he found no gold, but his journals contained much praise for the land and its fertility, noting that all the necessary ingredients were present for successful settlement; however, he was unable to succeed at colonization. Spanish interests were concentrated more in the southwest and Mexico rather than in the basin because of this nation's obsession with gold. Very little time and financial support were devoted to exploration

and development of the basin's resources or to the encouragement of permanent settlements. Spain was slow to act until other nations began to show an interest in the lands of the basin.

French explorers[19,20,23]

44. The Spanish are recognized as the first Europeans to explore the basin; however, it was the French who made the first serious attempts at settlement. For 131 years after the Coronado and De Soto visits, no one except the Indians saw the Arkansas River. Père Jacques Marquette, a missionary priest, and Louis Joliet, a veteran voyageur, reached the Mississippi-Arkansas confluence on 16 Jun 1673 during their exploration of the Mississippi River. Joliet's journal recorded the name of the Indians in the area as "Arkansea," representing the first record of the name "Arkansas."

45. In 1682 Robert Cavelier, Sieur de La Salle, claimed the entire drainage basin of the Mississippi River and the drainage basins of several smaller coastal rivers in western Louisiana and eastern Texas for France and named his discovery "La Louisiane" in honor of King Louis XIV. La Salle had plans to construct a series of forts from the Great Lakes to the mouth of the Mississippi River to secure the territory for France. A lieutenant of La Salle, Chevalier Henri de Tonti, accompanied him during much of his exploration of the Mississippi River, visiting the Mississippi-Arkansas confluence in 1683. In 1686 Tonti revisited the Arkansas Country and built a palisaded house along the Arkansas River on a concession granted to him by La Salle. He named his concession "Poste aux Arcansas"* (Arkansas Post), making it the first permanent settlement in the basin.

French control of the Arkansas-White-Red Rivers Basin[16,19,20,23-28]

46. By the end of the seventeenth century both France and Spain

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* C. B. Davis[19] states that the mountains of northwestern Arkansas and southwestern Missouri were referred to as "aux Arcansas," by the early French, meaning that they were in the land of the Arkansas Indians. The name was later anglicized by the English-speaking settlers to "Ozarks."

had claimed the lands of the basin, but both nations had been slow to establish themselves. France gradually expanded from New France into the Great Lakes and Mississippi Valley and later from the Gulf of Mexico inland. Spain's main interest was in Mexico and in the Rio Grande Valley around Santa Fe. The advance of settlement into the Arkansas-White-Red Rivers Basin began very slowly and continued to be slow until France began attempts to settle the Gulf Coast and the Lower Mississippi.

47. In 1699, Pierre Lemoine, Sieur d'Iberville, his younger brother, Jean Baptiste Lemoine, Sieur de Bienville, and 45 others left the Biloxi settlement to find and explore the Mississippi River. One exploratory party from this expedition went as far upstream as the mouth of a large river that they called the "Sabloniere" (later determined to be the Red River). In 1700, after returning to Biloxi, Iberville and Bienville initiated a second expedition into the Arkansas-White-Red Rivers Basin. After visiting the Taensas Indians near the present site of Newellton, La., in the Ouachita River drainage, Iberville sent Bienville westward to investigate rumors that the Spanish had come from Mexico to establish themselves within the limits of French Louisiana. Bienville first visited the villages of the Ouachitas and then turned southward crossing the Red River to the village of the Ouitchomis. With one of the Ouitchomis as a guide the expedition proceeded upriver to the country of the Natchitoches and on to that of the Yatasees and Cadodaquios in what is now the northwestern part of the state of Louisiana. Although Bienville found no Spanish settlements, it was not many years later that such rumors would become a reality.

48. The cautious Iberville knew that this western frontier must be watched and protected from Spanish settlement, so in May 1701 he dispatched Louis Juchereau, Sieur de St. Denis, to the Red River country to gather data on the region and its inhabitants. In 1714 St. Denis founded Fort St. Jean Baptiste, the beginnings of the town of Natchitoches, La., the oldest continually inhabited town in the present state of Louisiana. After construction of the fort had begun, St. Denis left the post for the country of the Tejas and other areas under Spanish jurisdiction to establish trade between Louisiana and Mexico. Most of the trade that

resulted from St. Denis's early efforts was overland from Natchitoches via the "Contraband Trail" (later known as the Natchitoches-Nacodoches Road). Along this trail an illegal trade also developed, much of the trade being in the form of horses stolen by the Indians from the Spanish and sold to the French. E. A. Davis[25] states that by the 1740's the trade between Louisiana and Mexico had become "...a significant source of income for the Louisiana colonists."

49. John Law convinced the French crown that he could operate the Louisiana colony at a profit and agreed to supply the colony with 6000 settlers and 3000 slaves. He organized the Company of the West on 6 Sep 1717 (reorganized in 1719 as the Company of the Indies) and sold shares throughout Europe. Law, himself, had plans to settle on a 12-square-mile concession just north of Arkansas Post. His plans were to establish a grand duchy with German and French serfs, reaping the bounty of the soil for his personal profit. In 1719 about 250 Germans and a number of slaves arrived to work Law's concession. Although Law was criticized for his schemes, he did succeed in bringing settlers to the colony. Prior to 1719 only a few persons had come to Louisiana and most of these had remained on the coast or in the new settlement of New Orleans, which had been founded in 1718 by Bienville. Other than Arkansas Post and Natchitoches there was little settlement activity in the basin during the latter years of French rule.

50. In 1721 Bienville ordered that an expedition be made to the headwaters of the Arkansas River, sending Jean Baptiste Bernard de la Harpe with 16 soldiers. The party had instructions to keep a journal on the navigability of the stream and to note particularly if there were any Spanish settlements. On 10 Mar 1721 the expedition proceeded up the Arkansas River, travelling for a month in search for a rock that was reputed to be of the purest emerald. They found no emeralds, but their travels did yield the location of a smaller rock formation that they labelled on their maps as "Le Petite Roche" (Little Rock).

Spanish Control of the Arkansas-
White-Red Rivers Basin[19,20,24,29-32]

51. By the 1762 secret Treaty of Fontainbleau, France ceded all

territory west of the Mississippi River plus the "Isle" of New Orleans to Spain, and by the Treaty of Paris (1763), England received the eastern Mississippi River basin (except New Orleans) and Canada. This meant that the lands of the Arkansas-White-Red Rivers Basin were now under Spanish control. Spain was slow to take possession of her new lands. It was two years after the Treaty of Fontainbleau had been ratified before the people in Louisiana were formally notified. Juan Kelly and Eduardo Nugent were sent in 1769 to the various posts and settlements that had been established by the French to obtain oaths of allegiance to Spain from the colonists and to survey these colonists and their livestock. The places visited by Kelly and Nugent included Natchitoches and its dependency, the post of Rapides (founded 1723), located on the Red River near present-day Alexandria, La. Arkansas Post had also become Spanish, its new name being Fort Carlos III of the Arkansas and later Fort San Esteban of the Arkansas. During Spain's tenure, Arkansas Post had a population of only 40 to 50 whites--mostly French--plus an unknown number of Indians.

52. Spain officially entered the American Revolution as an ally of France in 1779. Louisiana governor Bernardo de Galvez launched attacks and successfully took a number of British posts in West Florida. The American Revolution was ended by the Treaty of Paris (1783), and the United States gained title over all former British lands north of Florida, south of Canada and east of the Mississippi River. Spain held all lands west of the Mississippi plus Florida, which meant Spanish control of both banks of the Mississippi downstream from Natchez. Spain now had to contend with a new and independent neighbor, whom she feared would have designs on her holdings in Louisiana.

53. During the period of Spanish control, there were some attempts to settle the basin. A map entitled "Progress of Settlement" shows that in the portion of north and central Louisiana drained by the basin there were settlements in the following present-day parishes:[31]

<u>a</u>. Natchitoches and Sabine

<u>b</u>. Rapides

<u>c</u>. Avoyelles

d. Ouachita and Caldwell

e. Red River and DeSoto

Some of these settlements were extensions of the original French settlements, while others were populated by new settlers including some Acadians who had been deported by the English from their homeland in the present-day Maritime Provinces of Canada.[32]

54. The Treaty of San Lorenzo el Real, signed 27 Oct 1795, by the United States and Spain, adjusted the boundary between West Florida and the United States to 31 degrees north latitude, in line with the present Louisiana-Mississippi state boundary that runs east-west between the Mississippi and Pearl Rivers. This meant that Americans would now be living on the Mississippi River downstream from the mouth of the Yazoo River south to the new boundary. Spain felt a population buffer was required west of the Mississippi River to protect her interests. The low-lying lands immediately west of the Mississippi were considered unsuitable for settlement, so Governor Francisco Luis Hector, Baron de Carondelet, reasoned that the higher bluffs bordering the Ouachita River would be a better buffer zone. As a result, liberal land concessions were made in the vicinity of present-day Monroe, La.

American ownership of the Arkansas-
White-Red Rivers Basin[6,19,23,33-36]

55. In 1800 the Spanish crown returned the Louisiana colony to France by the Secret Treaty of San Idelfonso. Napoleon's representative for the transfer did not arrive in Louisiana until 30 Nov 1803, seven months after the purchase of Louisiana by the United States. Twenty days later the United States flag was hoisted in New Orleans.

56. During the first part of the nineteenth century a number of Americans explored the basin. LT Zebulon Pike left St. Louis in 1806 with orders to make peace between the warring Kansa and Osage tribes and to explore the sources of the Arkansas and Red Rivers. Pike mapped the Arkansas from its mouth to Colorado. Prior to the Louisiana Purchase the French traders from Arkansas Post had made numerous trips upriver to Belle Pointe at the confluence of the Arkansas and Poteau Rivers trading beads and other trinkets to the Indians for furs. The first permanent

white settlement there was a military post built by MAJ Stephen H. Long in 1817. Long named his post Fort Smith in honor of his commanding officer, GEN Thomas A. Smith, and the town of Fort Smith, Ark., grew around this settlement. In 1820 parties under Long's command made explorations into the Arkansas and Canadian River drainage basins. CPT John C. Fremont followed the Arkansas River for part of his westward explorations. CPT Fremont was led by Kit Carson up the Arkansas River to its confluence with Fountain Creek (near the present site of Pueblo, Colo.) in July 1843. CPT Fremont later learned that others (including some French trappers and even a party of Mormons bound for Utah several months earlier) had preceded him to this site.

57. Fur trappers and traders were responsible for much settlement in the central and western basin. Although this area was settled slowly at first, by 1850 numerous new sections had become developed. Cattlemen drove their herds from Texas to railheads in Kansas, which resulted in cowtowns springing up along the trails. Miners were responsible for many settlements, especially in Colorado. After the United States government confined most basin Indians to reservations, a number of whites moved in to claim what had been the traditional homelands of the Indians. In addition, the end of the Civil War and the passage of the Homestead Act lured many people to the basin.

58. Territories were carved out of the Arkansas-White-Red Rivers Basin, and out of these territories states were admitted to the Union. All of Oklahoma plus parts of seven other states were taken from the areas comprising the basin. Generally the admission of states progressed from east to west as the population of a territory became sufficient to qualify for statehood. By 1912 all basin states had been admitted to the Union in the following order:

| State | Date of Admission | Order of Admission |
|---|---|---|
| Louisiana | 30 Apr 1812 | 18th |
| Missouri | 10 Aug 1821 | 24th |
| Arkansas | 15 Jun 1836 | 25th |
| Texas | 29 Dec 1845 | 28th |

(Continued)

| State | Date of Admission | Order of Admission |
|---|---|---|
| Kansas | 29 Jan 1861 | 34th |
| Colorado | 1 Aug 1876 | 38th |
| Oklahoma | 16 Nov 1907 | 46th |
| New Mexico | 6 Jan 1912 | 47th |

## Economic and Social Trends

59. With the opening of new territories and the passage of the Homestead Act of 1862, settlers came to claim the choicest acreages in the bottomlands of the Arkansas-White-Red Rivers Basin. The first permanent settlers of the basin were farmers; thus, much of the early development of commercial centers was directly attributable to agricultural activities. Gradually other industries grew along with the transportation networks and urban centers necessary to support them. The following paragraphs deal with the development of agriculture, commerce and industry, transportation, and population and urbanization in the Arkansas-White-Red Rivers Basin.

### Agriculture[1,6,16,33-36]

60. The first farmers in the basin were probably the Poverty Point Indians who were present approximately 2000 years ago. Agricultural implements and other artifacts found with the Cave Dwellers and Mound Builders of Arkansas also suggest the early practice of agriculture in the basin. The French made slow starts at agriculture when they settled at Arkansas Post and later at Natchitoches. The limited numbers of settlers at these posts made farming difficult. At first many foodstuffs had to be imported from France or other colonies. It was during the time of John Law's Company of the West (paragraph 49) that the first serious attempts were made to bring farmers into the basin. Prior to 1717 the arriving settlers were generally attracted to the lands adjacent to the lower reaches of the Mississippi River and the Gulf Coast.

61. Agriculturally, the basin is a land of great contrasts. In the thousand miles from the headwaters of the Rocky Mountains to the Coastal Plain of Arkansas and Louisiana the climatic and physical

characteristics range between extremes, intensifying the problems of the farmers, ranchers, and forest managers. In the high, semiarid plains of the western part of the basin, it is difficult to grow crops without irrigation because of the low annual rainfall. In the low, humid areas of the Coastal Plain there is sometimes too much water, and it is often necessary to drain farmlands. Between these extremes, there are few areas without a moisture problem of some kind. Water erosion is a problem in all areas where there are sloping lands even in low-rainfall areas. In the semiarid sections of the west, the delicate surface soil must also be protected against wind erosion and the resulting dust storms.

62. Agricultural activities over much of the basin are highly specialized because the climate and soil type in many areas severely restrict the choice of viable crops and enterprises. For example, there are many thousands of acres suited only for limited grazing and other thousands of acres where wheat is ordinarily the only profitable crop that can be grown. In times of stress in the cattle business, the rancher has few, if any, alternative agricultural enterprises to which he can turn, and the wheatgrower can only turn to cattle raising, a change that would require many years for implementation. Because of the limitations imposed by climatic and soil conditions, much of the basin experiences a production disadvantage when compared with other areas of the United States.

63. Generally, the acreage in farms in the agricultural impact area of the McClellan-Kerr Waterway (paragraph 71) has not changed since 1969; however, the use and the productivity of that acreage has changed significantly. Cotton acreage has been reduced in favor of soybean production in the Oklahoma portion of the Waterway impact area, and soybeans and rice have replaced other crops in Arkansas. These changes have been accelerated because both soybeans and rice are major items in the recently increased volume of international trade in American farm products, and because the Waterway has given agricultural producers in the impact area ready access to international markets. Like the McClellan-Kerr Waterway, the Red River Waterway (paragraph 74) will provide an economic

means of moving agricultural produce to market; in addition, it will provide flood control for fertile agricultural lands along the Red River lowlands.

Commerce and industry[1,4,8,19,20,37]

64. Commerce in the Arkansas-White-Red Rivers Basin began in the colonial days. Initially, the Spanish were interested in the gold potential of the basin, but they found very little. Later the French actively pursued fur trapping and trading. Although the economy of the basin is today largely dependent upon agriculture as a basic source of income and employment, fossil fuels, metals, and nonmetallic minerals contribute significantly to the basin's economy. Manufacturing expanded rapidly during World War II and the post-war period but still is a much less significant part of the basin's economy as compared with the nation as a whole.

65. The development of oil and gas resources in the basin began about 1900. Reserves of petroleum and natural gas are located mainly in four areas: (1) The large central producing region extending southward from eastern Kansas, through east-central Oklahoma, and into northern Texas; (2) southern Arkansas and northern Louisiana; (3) west-central Kansas; and (4) the panhandle areas of Texas and Oklahoma. Currently, the basin is responsible for in excess of 25 percent of the nation's annual marketable oil and gas production.

66. Coal beds underlie approximately 24,000 square miles, or 8 percent of the basin. Coal occurs in all eight states and is produced in six. The original reserves of all classes of coal in the basin (semi-anthracite, bituminous, subbituminous, and lignite) are estimated to have been about 32 billion tons with less than 5 percent of the reserves having currently been used. Bituminous coals comprised nearly 98 percent of the original reserves. Commercial coal production began in the basin during the period 1850-1875, then expanded steadily until 1918 when peak annual production reached 10-1/2 million tons. Coal was used chiefly for domestic fuel and for generating steam in power plants and railroad locomotives. After World War I, oil and gas began to supplement coal for domestic and industrial fuel, and thus coal production

began to gradually decline until 1952 when the annual output had decreased to 6-1/2 million tons. As oil supplies dwindle, coal production is anticipated to again rapidly increase.

67. The many metal-mining districts situated wholly or partly within the basin produce significant percentages of the total national output of zinc, lead, germanium, gold, silver, molybdenum, and bauxite (aluminum ore). The production of copper, cadmium, mercury, tungsten, tin, iron ore, manganese ore, and pig iron has been of minor importance nationally, but has contributed materially to local and regional economics. The larger and more prominent mining districts in the basin are the tristate district of Missouri-Kansas-Oklahoma (zinc, lead), the Leadville district of Colorado (zinc, lead, copper, gold, silver), the Climax district of Colorado (molybdenum, tungsten, tin), and the Bauxite district of central Arkansas (aluminum ore).

68. The basin contains virtually unlimited resources of many nonmetallic minerals that are in demand by construction, chemical, and other industries. Cement is the leading commodity with other important nonmetallics being stone, clay products, sand, gravel, salt, lime, gypsum, barite, asphalt rock, glass sand, and tripoli.

## Transportation[6,16,19,31,37]

69. The various watercourses in the Arkansas-White-Red Rivers Basin were important to both the Indians and to the whites who followed. Early settlements were located in close proximity to the major streams to facilitate the movement of goods and settlers. Until some of the dense stands of forests were cleared and the swamps drained, these water routes were the only means of reaching many of the settlements. Surface transportation was limited to crude trails used by the buffalo and Indians and later by the Europeans.

70. There were 10 steamboats operating on the Arkansas River as early as 1820; by 1834 there were 18. At that time, however, the hand-operated keelboats and flatboats were carrying at least 90 percent of the business. A keelboat usually could make the trip from Little Rock to the confluence of the Mississippi and Arkansas Rivers and return in two or three weeks. The major steamboat period was from 1840 to 1870.

In 1850, 18 steamers made 115 trips up the Arkansas to Little Rock, while lighter boats were making regular runs to Fort Smith and even to Fort Gibson. Around 1870 the railroads began to provide better competitive schedules, which gradually forced the steamboats out of business.

71. The development of the McClellan-Kerr Arkansas River Navigation System for navigation, flood control, and hydroelectric power generation was the largest civil works effort ever undertaken by the CE prior to the 1970's. The project was authorized by Congress in the River and Harbor Act of 24 Jul 1946, and construction began in the 1950's. The entire 448-mile length of the waterway was opened for navigation in December 1970. The navigation channel begins at the confluence of the White and Mississippi Rivers, proceeds 10 miles upstream on the White to the man-made Arkansas Post Canal, then nine miles through the canal to the Arkansas River. The channel crosses the state of Arkansas and into Oklahoma to the mouth of the Verdigris River at Muskogee, Okla., and terminates 51 miles upstream on the Verdigris at Catoosa, Okla., near Tulsa.

72. Navigation on much of the Red River was virtually impossible until 1841 when Henry M. Shreve succeeded in clearing a 92-mile-long log raft from the main channel. The whole economy of the region both up and downstream from Shreveport had been transformed by the raft, sometimes in surprising ways. Though the effect on normal river traffic was adverse, the blockage of water had raised water levels in the bayous leading into the Red from eastern Texas. A brisk local trade had sprung up along these bayous, and the cotton of Texas found a way to market at New Orleans by devious streams that paralleled the Red. Ironically, clearing the main river caused the head of water in these streams to fall, thus cutting off the trade.

73. After 1908 a decline in the annual value of waterborne cargo began on the Red. From that time, river trade fell sharply until it was revived somewhat by the First World War. Even with this impetus, the average commerce value during the war years was only about half that of the 1890-1908 period. If river commerce was to be revived permanently and if the land along the banks was to be managed such that it would

produce the sort of bulk products that were best adapted for water movement, a whole new approach to river transportation was required. This need was underlined by the lagging social and economic development of the valley. Before the Civil War, the basin of the Red was sparsely inhabited, and no town had a population exceeding 5000 inhabitants. Development after the war was mainly directed towards opening the land for cotton production. The discovery of oil began to push the region toward a more diversified economy, and by the mid-20th century, manufacturing, trade, and services employed more workers than agriculture, yet the valley remained essentially underdeveloped.

74. The River and Harbor Act of 13 Aug 1968 authorized the Red River Waterway Project in accordance with House Document 304, 90th Congress, 2nd Session. The project provides in part for a 9-ft stabilized navigation channel extending from the Mississippi River through Old River and Red River to the vicinity of Shreveport and then through Twelvemile and Cypress Bayous to a turning basin in the Lake O' The Pines (Ferrells Bridge Reservoir) near Daingerfield, Tex. Eight locks and dams will provide the required depths for navigation. The project also makes provisions for the extensive use of channel stabilization structures.

75. Besides the McClellan-Kerr Waterway and the Red River, waterborne commerce has been reported on the Ouachita and Black Rivers (Ouachita-Black Waterway) and the White River. Plans are under way on the Ouachita-Black Waterway to replace the six existing locks and dams with four larger ones. Two of these (Jonesville and Columbia) have been completed; the other two (Felsenthal and Calion) are under construction. When completed, this project will provide a 9-ft navigation channel to Camden, Ark. Freight and passenger traffic in the Arkansas-White-Red Rivers Basin during calendar year 1977 is provided in Table E2.

76. The basin is now served by an excellent system of highways, railroads, pipelines, and airlines. This vast network handles transportation within the basin, and provides connections to points outside the basin. In Oklahoma City, for example, there are 5 passenger airlines plus a number of major bus, truck, and rail lines, while Wichita has five airlines, four major rail freight lines, 51 trucking companies, and

one bus line. Other major transporation centers, in the basin include Tulsa, Little Rock, Shreveport, Colorado Springs, and Springfield, Mo.

Population and urbanization[16,19,31,38-40]

77. Prior to the arrival of European explorers in the Arkansas-White-Red Rivers Basin, the region was occupied by Indians in a number of different settlements. Population figures for the Indians are difficult to obtain; however, there were probably several thousand present by the time the Spanish arrived. The French settlements adjacent to military posts were very small. A 1722 census of Natchitoches taken by the French[38] showed that there were 60 inhabitants. No doubt this census accounted for most of the colonists, but excluded the Indian population (except slaves) and the fur traders. In 1744 Arkansas Post had a population of 12 white males and 10 slaves; by 1785 there were 196 inhabitants.

78. The population grew in the French colonial period as a result of John Law's ambitious schemes, with several large land concessions being granted. Later, Spanish grants also brought about increases in population especially in the Ouachita River Subbasin. The greatest increases came with the period of American jurisdiction as a result of the opening of territories to settlement, the acquisition of Texas after the Mexican War, and the passage of homestead legislation.

79. Cities were established and grew when settlers moved westward. Table E3 shows, in chronological order, selected basin cities and their dates settled. In 1975 there were 18 Standard Metropolitan Statistical Areas (SMSA's) as follows:

| State(s) | SMSA |
|---|---|
| Arkansas | Fayetteville-Springdale<br>Little Rock-North Little Rock<br>Pine Bluff |
| Arkansas-Oklahoma | Fort Smith |
| Colorado | Colorado Springs<br>Pueblo |
| Kansas | Wichita |

(Continued)

| State(s) | SMSA |
| --- | --- |
| Louisiana | Alexandria<br>Monroe<br>Shreveport |
| Missouri | Springfield |
| Oklahoma | Lawton<br>Oklahoma City<br>Tulsa |
| Texas | Amarillo<br>Sherman-Denison<br>Wichita Falls |
| Texas-Arkansas | Texarkana |

In the next several years, the population of most of the SMSA's is expected to increase. Much of the increase will be attributed to expanded market areas and diversification of industry; no doubt the McClellan-Kerr and Red River waterways will accelerate the population increases. The rural population is expected to decrease as many leave the farm for work in urban areas. Table E4 shows basin population for selected years between 1900 and 1970.

## Land-Use Development

80. Land use and land-use change with respect to time play significant roles in defining the characteristics of a basin's sediment regime and bed-material gradation. Quantitative land-use information (i.e. maps or statistical data) is difficult to obtain on a basin-wide basis especially for different time frames. Many Federal, state, regional, and local agencies are engaged in the process of mapping land use, but the variations in methods used to obtain these data, their reliability, and even the choice of parameters used to quantify land use are widely diversified.

81. In all eight of the states drained by the Arkansas, White, and Red Rivers, land-use mapping is in progress. The following land-use products have been published:

a. Arkansas. The USDA Soil Conservation Service (SCS) published a Conservation Needs Inventory (CNI)[41] in 1969 containing land-use data by counties.

b. Colorado. The Colorado Land-Use Commission was chartered by the state legislature for the purpose of mapping land use. In 1974, this agency published a comprehensive folio of statewide land-use maps[42] that reflect the status of land use in that state in July 1973. These maps were produced in cooperation with the SCS and are based on field observations. The SCS also compiled a CNI[43] summarizing the land use and land-use treatment needs for Colorado in 1967 including a series of land-use maps for individual Colorado counties.[44]

c. Kansas. The SCS published a CNI[45] for Kansas in 1969. The Space Technology Laboratories of the University of Kansas prepared a "Kansas Land-Use Map"[46] in 1974 in cooperation with the Planning Division of the Kansas Department of Economic Development by visually interpreting Landsat imagery for summer 1973.

d. Louisiana. The U. S. Geological Survey (USGS) through its Land Use and Data Analysis (LUDA) program has produced land-use maps[47] keyed to the USGS 1:250,000 scale topographic maps, covering the state of Louisiana. There is a summary by parishes of the area in acres for each classification used in LUDA maps.[48] A CNI[49] for the state was issued in 1969.

e. Missouri. State agencies and universities in Missouri have prepared reports[50,51] describing techniques for mapping land use with Landsat and other remote imagery. In addition the SCS published a CNI[52] in 1970.

f. New Mexico. The only suitable land-use data that cover New Mexico on a uniform basis are those contained in the CNI[53] published by the SCS in 1970.

g. Oklahoma. The SCS has prepared land-use maps[54] by counties. In addition, the SCS issued a CNI[55] in 1970. Current projects include one by the Oklahoma Conservation Commission to update land-use data by using Landsat information from the National Aeronautics and Space Administration and to computerize land-use data obtained from the SCS.

h. Texas. The CNI[56], published by the SCS in 1970, is the only available publication containing statewide land-use data.

82. Land-use data for the eight states[40-56] have been mapped by political units rather than by watershed boundaries. The CNI's provide

land-use data by county for 1958 and 1967. Data for years prior to 1958 are available by county from Federal decennial and agricultural censuses. Both the CNI's and the census data must be adjusted such that they are compatible with the watershed boundaries rather than with the established political boundaries. The exception to this are the data for 1967 that are stored on magnetic tape at the Iowa State University Statistical Laboratory, Ames, Iowa that can be retrieved by either basin unit or political entity.

83. The following categories taken from the CNI's have been used to quantify land-use change in the Arkansas-White-Red Rivers Basin:

a. Cropland. Irrigated and nonirrigated land that has been tilled within the last five years, including land planted in hay crops or used for orchards and vineyards.

b. Pasture and rangeland. Pasture is defined as land planted in introduced grasses primarily for livestock consumption; rangeland includes all natural grazing lands and lands seeded with a mixture of native climax-adapted grasses for grazing use; cropland abandoned for 5 years where the intended use is grazing; and wild hay, native hay, or rangeland meadow.

c. Forest. Commercial and noncommercial woodlands and windbreaks of one acre or more; U. S. Forest Service and other Federal lands containing 10 percent (crown coverage) or more trees capable of producing timber or wood products or of exerting an influence on the water regime; and grazing woodlands.

d. Other land. Farmsteads, roads, feedlots, ditch banks, fence and hedge rows, rural nonfarm residence, other rural lands not suited for agriculture (e.g. marshes); Federally owned land not leased for grazing or for forestry; cities, towns, and built-up areas more than 10 acres in size; industrial sites, railroads and railroad yards, cemeteries, airports, golf courses, parks and recreational acres; institutional and administrative sites; ponds, lakes, reservoirs, and other water bodies more than two acres in size; and any other areas that do not meet the requirements of a, b, or c.

Land-use data for the Arkansas-White-Red Rivers Basin for four selected years are provided in Table E5 by the four categories defined above;*

* Data for 1860 were collected for only three categories: cropland, pasture and range, and forest and other land (see Table E5).

the appropriate documentation of source material for each year is given below:

| Year | References(s) |
|---|---|
| 1860 | 57 |
| 1910 | 40 |
| 1935 | 58 |
| 1967 | 40,43,45,49, 52,53,55,56 |

## PART III: CHARACTERIZATION OF SUSPENDED-SEDIMENT REGIME

84. Sediment yields over the Arkansas-White-Red Basin are considered to be high, with much of the drainage area experiencing annual yields in excess of 1000 tons per square mile. Maximum yields occur through the central and southeastern parts of the basin; minimal yields are experienced in the western and northeastern portions of the basin (Figure E7). The amount of sediment discharge at any location within the streams of the basin is a function of many variables that fall into two general categories: the characteristics of the drainage basin and the characteristics of the stream through the reach in question. Important drainage basin characteristics include physiography and geology (paragraphs 13-18), soils (paragraph 19), climate (paragraphs 20-23), hydrology (paragraphs 24-36), and vegetation (paragraph 37). In addition, stream width, velocity, slope, temperature, and turbulence, bed and bank materials, particle size and type, and control conditions both upstream and downstream of the reach of interest must be considered in developing an understanding of the suspended-sediment regime.

85. Under present conditions, estimated annual subbasin sediment yields range from over 100 million tons in the Cimarron-North Canadian-Canadian Rivers Subbasin to slightly over 6 million tons in the White River subbasin. Sediment yields in the subbasins are discussed below. A summary of estimated annual sediment yields for the seven subbasins is provided in Table E6.

86. Sediment yield in the Cimarron-North Canadian-Canadian River Subbasin is high in the eastern part of the subbasin (>1800 tons/mi$^2$/yr) and low in the western half (<480 tons/mi$^2$/yr) with the exception of the plains adjacent to the Upper Cimarron River where annual yields up to 1800 tons/square mile occur. Prior to the closure of Keystone Dam in 1964 (the confluence of the Arkansas and Cimarron Rivers), the Cimarron River was a heavy suspended-sediment contributor to the Arkansas main stem. Data developed from the samples collected at Perkins, Okla. (30 miles upstream from the present upper end of Keystone Reservoir) indicated an average annual load of 9,550,000 tons (based on 388 samples

taken from July 1939 through September 1958).[59] The Arkansas and Cimarron now contribute approximately the same amount of sediment material to Keystone Reservoir; however, the Arkansas generally has flow three times greater than that of the Cimarron. Studies conducted on the upper reaches of the Cimarron[60] indicate that the suspended sediment is predominantly silt and clay, with a very minor percentage of sand transported in suspension. Much of the sediment load of the Cimarron River passing through this reach is derived primarily from the arid mountains, mesas, and canyons of northern New Mexico and southern Colorado. The Canadian River is a heavy sediment-bearing stream with a shifting bed and unstable banks, causing this stream to carry the largest volume of suspended sediment in this subbasin.[61] The average annual suspended-sediment load passing Calvin, Okla. (at mile 93.7 on the Canadian River immediately upstream from its confluence with the North Canadian) varied from 17,900,000 to 28,700,000 tons per year (based on three methods of computation and 910 samples taken from October 1930 through September 1958).[61] The average annual sediment load determined from samples taken at Whitefield, Okla. (at mile 18.8 on the Canadian River upstream from its confluence with the Arkansas River) ranged from 50,300,000 to 34,800,000 tons per year (based on three methods of computation, and 1,042 samples taken from June 1938 through September 1958);[61] this range generally reflects the suspended sediment contribution of the Canadian to the Arkansas prior to closure of Eufala Dam in 1964.

87. Annual sediment yields in the Lower Arkansas River Subbasin ranges from less than 480 tons per square mile in the eastern part of the subbasin to yields of 480 to 960 tons per square mile in the western areas. Prior to the placement of several upstream sediment retention structures, the suspended-sediment loads passing through the subbasin were considered to be heavy, even though they were derived primarily from upstream sources, with 50 percent of this load attributable to Canadian River discharge, 25 percent to the Arkansas River upstream from Tulsa, and the remainder from tributaries in eastern Oklahoma and Arkansas.[62] Since the closure of the upstream structures (1963-1970), the main-stem load has been reduced appreciably, although the Arkansas

still remains as the major suspended sediment contributor to the Mississippi River in the reach downstream from Cairo.

88. Annual sediment yields in excess of 1000 tons per square mile are present throughout much of the Lower Red River Subbasin, with yields in excess of 1800 tons per square mile in the headwaters areas of many Red River tributaries in Oklahoma and Texas. As a result, the Red River is a heavy suspended-sediment carrier with an annual estimated discharge of 40 million tons at its mouth even with all authorized sediment retention structures in operation.[4]

89. Sediment yields in the Ouachita River Subbasin vary from less than 480 tons/$mi^2$/yr in the eastern part of the drainage to as much as 1800 tons/$mi^2$/yr in the western reaches. Croplands are responsible for more erosion than any other land-use activity in this subbasin. Although yields per unit area are higher for gullies, roads, gravel pits, and streambanks, the total yield from these sources is somewhat less than for cultivated land.[5] Extensive clearing of brush and woodland within the subbasin has often left the soil without adequate protection from erosion, most of which occurs in the spring immediately after the land is freshly tilled.

90. Annual sediment yields in the Upper Arkansas Subbasin vary from less than 480 tons per square mile in the Rocky Mountain foothills and parts of western Kansas to in excess of 1800 tons per square mile in the lower subbasin. The low yields in the western part of the subbasin are generally attributable to meager precipitation and runoff or low topographic relief.[63] Most of the suspended sediment passing through the reach of the Arkansas River in Kansas is clay and silt, and owing to the extensive loess deposits of western Kansas, there is little composition change downstream at least to the Kinsley area. The suspended-sediment loads of the Arkansas now actually decrease through western Kansas due to irrigation diversions; in addition, much of the land adjacent to the main stem does not contribute drainage or sediment.[60] In the lower part of the subbasin the initiation of most sediment transport results from thunderstorm activity in the spring and summer that tends to minimize the stabilizing effects of vegetation.

91. Annual sediment yields in the Upper Red River Subbasin vary from less than 480 tons per square mile in the Texas Panhandle to over 1800 tons per square mile throughout the entire eastern half of the subbasin. The unit annual sediment yield in this subbasin is over 2000 tons per square mile which represents the highest value in the Arkansas-White-Red Basin (Table E6). The impact of the high yields on suspended-sediment loads in the Lower Red River was greatly mitigated by closure of Denison Dam in 1944.

92. Sediment yields in the White River Subbasin are by far the lowest in the Arkansas-White-Red Basin on both a unit and total yield basis; annual yields are less than 480 tons per square mile over the whole subbasin. The White River and its tributaries carry only a small amount of suspended sediment at low stages and are generally classed as clear-water streams; however, the bed slopes are moderately steep in the upland areas, and velocities during high stages are great enough to carry a significant amount of suspended sediment and bed-load material, although admittedly small when compared with streams in most other parts of the basin.[8]

## Cultural Influences on Suspended-Sediment Regime

93. In addition to the use of the land for urban and agricultural development, channel improvements, reservoirs, and dredging (paragraphs 124-126) have had impacts on the suspended-sediment regime of the Arkansas-White-Red Rivers Basin.

### Channel improvements

94. Prior to recent channel improvements, floods were always a problem along the lower Arkansas. Upstream from Little Rock the damage was never serious because of the high bluffs on both banks. The first major flood of record apparently was one of the worst. Heavy rains in the spring of 1833 caused the river to rise to a stage of 34.6 ft in June. The normal river stage for July in Little Rock is 6.6 ft and flood stage is 23 ft. Water stood 15 ft deep in the bottomlands from Arkansas Post to Little Rock. Thousands of acres of cotton and corn were swept

away, and plantations ruined. Next to the historic flood of June 1833, a record gage reading of 33 ft was reached at Little Rock on 19 Apr 1927. During this flood only the roofs of houses were visible at Arkansas City; residents camped along the levee for days. Human suffering greater even than that exacted by the 1927 flood occurred in 1937 when main levees broke and inundated more than 100,000 acres in eastern Arkansas. This flood came in January and was followed by a sleet storm that brought added misery to thousands of refugees sheltered by National Guard tents.

95. The first project for improvement of the Arkansas River was authorized by the River and Harbor Act of 3 Jul 1832. The work under this act consisted of removing obstructions and constructing temporary wing dams between Fort Smith and the mouth of the river.[64] The River and Harbor Act of 11 Aug 1888 adopted a general plan for improving the river for navigation from Wichita to the mouth by contraction works and the removal of shoals. Dikes and revetments were built at Redland (mile 380) and Bruce Island (mile 375), Okla., and at Fort Smith, Van Buren, Dardanelle, Little Rock, Pine Bluff, and Red Fork (mile 31.3), Ark. Open-channel improvements were made on an experimental basis in a 22-mile reach near Little Rock, but the controlling depth was only 1.5 ft for almost 3 months during the 1897 low water. As a result, further construction of permanent works was discontinued. The McClellan-Kerr Arkansas River Navigation System was authorized by Congress in the River and Harbor Act of 24 Jul 1946. Construction began in the 1950's and was completed in December 1970 (paragraph 71). The CE maintains minimum channel width of 300 ft for the White River and Arkansas Post Canal, 250 ft for the Arkansas River, and 150 ft for the Verdigris River. The waterway has been canalized throughout its length by construction of 17 locks and dams.

96. The Federal Government started improving navigation on the White River in 1870, beginning with snagging operations downstream from DeValls Bluff, Ark., in connection with a similar operation on the Mississippi River. The first direct appropriation for White River improvement was made by the River and Harbor Act of 3 Mar 1871.[8] This Act provided for snagging operations downstream from Jacksonport, near the

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mouth of the Black River. The existing navigation project on the lower White River was authorized by the River and Harbor Act adopted 13 Jul 1892. Although the Act did not specify any channel dimensions, a depth of 4-1/2 ft and a width of 100 ft are accepted as satisfying its requirements. The project provides for maintaining a channel of these dimensions between the mouth of the river and Batesville by snagging, dredging, and contraction works. Three lock and dam structures were completed by the CE at Batesville (mile 299.8), Earnharts (mile 308.3), and Walls Ferry (mile 320.1) in 1908; these structures were maintained until 1952. Downstream from Newport one permeable dike and several stone and brush dikes were constructed; however, these works were not effective in providing suitable navigation depths and, as a result, were not maintained. Today nearly all of them have completely disappeared. Because of a decline in the volume of traffic, dredging was discontinued after 1942 and snagging and other maintenance work in 1951. In 1961, increased river traffic and requests by local interests prompted the Chief of Engineers to approve resumption of maintenance upstream to Augusta. The White River Navigation District Commission and individual waterway users later requested that greater channel dimensions be provided because of increased river traffic. A favorable report, prepared by the Memphis District, was approved by the Chief of Engineers, 11 March 1968; in 1969 minimum channel dimensions were increased downstream from Augusta to provide a width of 125 ft and a depth of 5 ft.

97. Channel modifications on the Red River were initiated by Henry M. Shreve, who was appointed civilian superintendent of improvements on the Mississippi and Ohio Rivers in 1826.[33] Shreve designed and built the first snag boats, and under the general supervision of the CE, worked indefatigably to clear banks and channel. His work eventually extended to the Red River, which was blocked by a gigantic log raft. At its greatest extent in 1828 the Red River Raft was 92 miles in length, extending from Loggy Bayou, 65 miles downstream from the present site of Shreveport, to Hurricane Bluffs, 27 miles upstream from that city. At the urging of the Chief of Engineers, Shreve attacked the raft, snagging and blasting the dead trees, and blocking up bayous by which the river

had found ways around the obstacle. Explosives and steam engines had to be used to open a way through this rough, resilient, matted obstacle that became larger with the timber brought down by each high water. Shreve eventually broke through the raft, restoring a moderate current to the main channel.

98. The raft periodically re-formed between 1828 and 1841, requiring an expenditure of over $425,000 for its removal. The decline in Federally financed stream improvements interrupted the work. Finally in 1841 appropriations failed entirely. During a brief revival of civil works activities in 1852, another $100,000 was appropriated, and the channel to Shreveport was reopened. New appropriations were made in 1872, but when Federal work resumed, the years of neglect and war had left their mark.

> "...The river above Shreveport, La., was closed by a raft 32 miles long and growing constantly. Below Shreveport the enlargement of an outlet through Tones Bayou was depleting the main channel and threatening its closure to navigation. At Alexandria, La., the falls were impassable at low stages. Navigation was difficult and dangerous at all places and at all times. The channel shifted frequently, and at flood the river overflowed the entire raft region. The banks were heavily timbered and each flood caused them to cave or slide."[33]

Despite a multitude of problems, small but regular appropriations enabled a gradual improvement to take place. The raft was broken in 1873, and the major outlets were gradually closed off. Scour increased the channel depth, and the perils of navigation that had claimed nearly 200 steamboats through 1887 steadily lessened. To prevent new snags from falling into the channel, banks were cleared and the worst shoals were dredged. The CE began efforts to stop bank erosion by building dikes and revetments. A period of optimism over the river's future followed. In 1909, the Vicksburg Engineer Office reported that at high water the Red River was navigable as far as Denison, Tex., 800 miles upstream from the Atchafalaya confluence.

99. In addition to his channel clearing activities, Shreve tried several experiments with cutoffs, including one across Turnbull's Bend

where the Red River entered the Mississippi and the Atchafalaya left it. His plan was to shorten the river so that the steamboats could avoid shoals that had formed downstream from the Red, but his work created five distinct channels--the Mississippi, the Red, and Atchafalaya, and the Upper and Lower Old Rivers (as the branches that had formed Turnbull's Bend came to be called), which plagued the CE until the middle of the 20th Century.

100. Channel improvements currently continue on the Red. The River and Harbor Act of 13 Aug 1968 authorized the Red River Waterway Project in accordance with House Document 304, 90th Congress, 2nd Session. The project provides in part for a 9-ft stabilized navigation channel extending from the Mississippi River through Old River and Red River to the vicinity of Shreveport (paragraph 74).

Bank stabilization

101. Over 255 miles of bank revetment and 160 miles of dikes have been placed on the Arkansas River from its mouth through mile 319 (much of this in connection with construction of the McClellan-Kerr Waterway). The majority of the bank protection works in the White River drainage have been placed to protect highway and railroad bridgeheads, with less than 10 miles of revetment being placed strictly for bank protection. Approximately 132 miles of bank revetment and dikes have been constructed along the Red River through mile 221 (Index, Ark.); additional protection will be placed as part of the Red River Waterway Project.

102. Bank stabilization works placed as part of the McClellan-Kerr Waterway have prevented the loss of an estimated 6,050 acres of land from mile 19 through mile 310; in addition completion of these works have resulted in 3,410 acres of land accrual as the direct result of sediment depositing behind dikes and revetments.[65] No information is available regarding the amount of land lost each year in the White Basin due to bank caving. On the Red River 2100 acres are lost each year downstream from Index, Ark.; upstream from Index 1000 acres are lost annually. The total area potentially threatened below Denison Dam is 500,000 acres, of which two-thirds is downstream from Index. Although many bank protection works have been placed in the Arkansas-White-Red Basin, some 26 percent

of the total channel miles are still actively eroding (1979). This erosion results in an annual property loss of $62.4 million, and would require $22.0 million to restore the banks to their original condition.

Reservoirs

103. The McClellan-Kerr Arkansas River Navigation System consists of 17 locks and dams providing a total lift in excess of 500 ft for the 448-mile length of the waterway. All but four of these structures are run-of-the-river and have no sediment retention capacity. The remaining four, Dardanelle, Ozark, Robert S. Kerr, and Webbers Falls have a total design storage capacity of 1,293,000 acre-ft (Figures E8 and E9 and Table E7). Upstream from the termination of the navigation project, Keystone, Kaw, John Martin, and Pueblo reservoirs provide an additional 4,286,800 acre-ft of storage capacity for the Arkansas main stem. Thirty-nine dams on tributaries to the Arkansas have a collective capacity of 19,560,100 acre-ft, making a total of 25,139,900 acre-ft for the Arkansas drainage.*

104. Three major dams have been placed on the main stem of the White River: Bull Shoals, Table Rock, and Beaver; the total design storage capacity for these reservoirs is 10,822,000 acre-ft. Three other dams on tributaries to the White have a collective capacity of 5,240,000 acre-ft, making a total of 16,062,000 acre-ft for the subbasin.*

105. The 141-ft lift specified for the Red River Waterway to Shreveport requires five locks and dams. These structures will be run-of-the-river projects, and will not have significant sediment retention capability. The only major sediment retention structure currently in operation on the Red is Denison Dam which has an average annual sediment inflow of 20,508 acre-ft. In the Red River drainage upstream from Denison, 11 dams provide 2,306,700 acre-ft* of design storage capacity. Downstream from Denison, 36 dams on tributaries to the Red have a total design storage capacity of 18,353,900 acre-ft, thus providing a total of 26,042,600 acre-ft for the Red River drainage.

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* Reservoirs of less than 75,000 acre-ft design storage capacity are not included in this statistic.

106. The 101 dams in the Arkansas-White-Red Basin provide a total design storage capacity of 62,004,500 acre-ft. In addition these structures provide sediment retention capability for 93 percent of the land area in the Arkansas drainage, 39 percent in the White, and 86 percent in the Red; or 86 percent of the whole basin. Not included in the design storage capacity totals are reservoirs of less than 75,000 acre-ft storage capacity. Many such small projects are in operation in the more arid regions of the basin for irrigation and conservation purposes. Through the years, a multitude of stock dams, fish and recreation lakes, and farm ponds have also been built in the basin to intercept the runoff from small drainage areas. Although the total storage capacity of these impoundments is not accurately known, this storage has undoubtedly had some positive effect on the effort to reduce the sediment flow in the Arkansas-White-Red Basin.

## History of Suspended-Sediment Sample Collection

107. Suspended-sediment samples were collected at 17 stations in the Arkansas-White-Red Rivers Basin prior to 1931 (Table E8). The first recorded repetitive daily collection of suspended-sediment samples on the Arkansas River was at Pine Bluff, Ark., from 20 Feb through 8 Jul 1879.[66] Six samples were taken at each of four points across the width of the stream, two at the surface, two at mid-depth, and two at 1 ft above the bottom, making a total of 24 samples for each day of observation. A physical description of the sampling device was not included with the reported documentation. During this period, the maximum daily water discharge was 126,456 acre-ft; the mean, 29,462 acre-ft; and the minimum, 7,581 acre-ft. The maximum daily suspended-sediment load was 343,686 tons; the mean, 20,589 tons; and the minimum, 544 tons. These statistics represent the first published suspended-sediment information for the Arkansas River drainage.

108. Suspended-sediment samples were first collected on a repetitive basis on the White River at Clarendon, Ark.[66] Samples were taken from the stream on a daily basis from 19 Jan through 26 Jun 1879. The

device used to collect the samples consisted of a copper cylinder 12 in. long and 4 in. in diameter with sufficient lead on the inside of the lower part to sink the sampler. The sampler had two leather valves opening upward--one at the top and the other at the middle. The suspended-sediment samples were collected from three locations at the surface, about one-fourth, one-half, and three-fourths of the distance across the stream. Approximately equal portions of water were taken and placed in the same glass jar. At points beneath those at surface, and about 6 in. from the bottom three like quantities were taken and placed in another jar. Onshore (after being well shaken) six fluid ounces were measured from each jar and placed in two other jars marked surface and bottom respectively. When five days' collections had been made in this manner, the jars were set aside, and another five days' collection commenced. After 14 February, in addition to the collections made at the surface and bottom, three others were made at mid-depth, making in all nine contributions for each day. During the sampling period, the maximum daily water discharge was 77,091 acre-ft; the mean 38,680 acre-ft; and the minimum, 11,826 acre-ft. The maximum daily suspended-sediment load was 3,447 tons; the mean, 1,888 tons; and the minimum, 458 tons. These data represent the first published suspended-sediment information for the White River drainage.

109. The first recorded repetitive collection of suspended-sediment samples in the Red River drainage was at Alexandria, La.[66] Samples were taken from the Red River on a daily basis from 24 Feb through 1 Jul 1879. Surface and bottom samples were collected at one-fourth, one-half, and three-fourths the width of the stream cross section, and the collections for 5 days were combined into one set. A physical description of the sampling device was not included with the reported documentation. During this period, the maximum daily water discharge was 98,534 acre-ft; the mean, 50,742 acre-ft; and the minimum, 16,451 acre-ft. The maximum daily suspended-sediment load was 83,233 tons; the mean 26,996 tons; and the minimum, 4,692 tons. These statistics represent the first published suspended-sediment information for the Red River drainage.

for a station where daily suspended-sediment samples were not taken, the following criterion was used: samples must have been taken on at least 10 days during each month of the year when there was flow; the available data was then adjusted to an annual basis. Data obtained by grab sampling techniques were deleted from consideration for the purposes of this study.

## Long-Term Trends in Suspended-Sediment Regime

114. The Arkansas River is the major suspended-sediment contributor to the Mississippi main stem downstream from Cairo. The hydraulic and sediment regimes of the Arkansas have been significantly altered in recent years due to improved land-use practices, channelization, and the construction of several flood control and navigation structures which trap sediment. Prior to the construction of these impoundments, the annual suspended-sediment load passing Little Rock was in excess of 100 million tons (based on 1939-1953 data; Figure E19). The load passing this station is generally regarded as reflecting the contribution of the Arkansas to the Mississippi River.

115. The major main-stem suspended-sediment contributors upstream from Little Rock prior to placement of the structures (paragraph 114) were the Canadian River (49.9 million tons per year), the Verdigris River (16.3 million tons per year), the Cimarron River (9.6 million tons per year), and the reach upstream from the confluence of the Arkansas and Cimarron (10.7 million tons per year).[78] The suspended-sediment load below the confluence of the Arkansas and Cimarron Rivers was substantially reduced by closure of Keystone Dam in 1964. The sediment inflow from the Canadian River significantly declined as a result of the construction of Eufala Dam (1964). Downstream sediment loads were further reduced by closure of four main-stem structures: Dardanelle (mile 205.5), Ozark (mile 256.8), Robert S. Kerr (mile 336.2), and Webbers Falls (mile 368.9).

116. The effect of the impoundment closures can be assessed by examining the records of sediment sample collection stations in the lower

reaches of the Arkansas River in terms of the average annual discharge and the average suspended-sediment load experienced during the pre-dam construction period (before 1963), the transition period between pre-dam and post-dam construction (1963-1970), and the post-dam construction period (after 1970).

| | River Mile | Average Annual Discharge (acre-ft) Before 1963 | 1963-1970 | After 1970 |
|---|---|---|---|---|
| Van Buren, Ark. | 219.5 | 23,855,900 | 16,650,286 | 28,702,446 |
| Little Rock, Ark. | 141.5 | 33,943,091 | 21,102,785 | 35,427,160 |

| | River Mile | Average Annual Suspended-Sediment Load (tons) | | |
|---|---|---|---|---|
| Van Buren, Ark. | 219.5 | 65,256,600 | 10,925,634 | 10,758,063 |
| Little Rock, Ark. | 141.5 | 92,765,136 | 11,886,548 | 12,069,439 |

Thus, the upstream improvements have reduced the sediment load at Little Rock to 12 percent of its natural value, probably reflecting a similar decrease in the contribution of the Arkansas to the Mississippi main stem.

117. Annual sediment yields in the White River drainage are less than 480 tons per square mile; consequently, the suspended-sediment loads found in the streams of this subbasin are very low.[79] The average annual suspended-sediment contribution of the White River to the Mississippi River's load is estimated to be less than 4 million tons.

118. The suspended-sediment load of the Red River upstream from Denison Dam is effectively trapped when the load reaches the reservoir; practically none of this load is passed into the lower Red River.[80] Downstream from Denison Dam the average load of the Red increases again (Figure E20) reaching a maximum of 40,000,000 tons per year at its mouth.

119. Although local changes do occur, most alluvial rivers tend to consistently maintain the same overall geometry through the years, because erosion in bends is accompanied by accretion on points.[4] Thus, the continuing discharge of sediment from the downstream end of a reach is generally dependent only on the inflow of sediment from tributaries into the reach. The Red River, however, has two other major sources of sediment. One is the continuing degradation of its streambed, and the

other, which is related to the first, is the failure of the alluvial process after bank caving to restore the banks to their former elevation. The latter effect is of particular significance upstream from Shreveport. The alluvial banks in this reach reflect a regimen that was present prior to 1873. In that year, a massive natural obstruction in the river near Shreveport, known as the Red River Raft (paragraphs 97 and 98), was removed, resulting in a reduction in the streambed elevation by as much as 14 ft. This reduction in turn caused a major decrease of flood elevations, and, concomitantly, prevented the restoration of caved banks to their original elevations prior to caving.

120. To gain some quantitative knowledge of the influence of this phenomenon, a study of a 28-mile reach of the river (mile 193 to mile 221) was made in 1958. Comparison of transverse sections from the surveys of 1930 and 1950 showed that the average bankfull elevation had decreased 2.3 ft during the 20-year period, during which time the river had shifted its position by at least its own width throughout the 28 miles. The study indicated an annual loss due to the reduction in bank elevation of 72,800 cu yd of material per river mile. From Shreveport to Fulton, this would indicate an annual loss of 9,848,000 cu yd. From Fulton to Denison Dam, the indicated loss computed on the same basis, would be 9,828,000 cu yd a year. Under the impetus of forces resulting from the removal of the Red River Raft, the riverbed at Shreveport has progressively deepened as the stream seeks to establish a new equilibrium. Based on surveys and discharge and stage data for the period 1928 to 1945, the rate of streambed depression was about 0.12 ft per year. For an average streambed width of 800 ft, the depression represents an annual loss of about 19,000 cu yd per mile.

121. Part of the ongoing Red River Waterway Project includes bank stabilization in the reach downstream from Shreveport; this action will reduce the supply of sediment available for transport.[81] Until the complete river system upstream from Shreveport is stabilized, however, the same amount of sediment will have to be transported through the downstream reach because of the large volume of material that will continue to pass Shreveport. There will be little modification of the current

sediment regime as a result of the navigation dam construction below Shreveport; proposed operational plans will require that the gates be fully open at flows above half-bankfull when most of the sediment transport occurs.

# PART IV: CHARACTERIZATION OF BED-MATERIAL GRADATION

122. Although the mineralogic composition of bed material varies only as a function of geologic source, or parent rock, the gradation of this material is a function of both natural phenomena (i.e. geology, physical and chemical alteration, hydrology, and climatology) and cultural practices (i.e. agricultural management, engineering adjustments, and dredging). The cultural influences on the bed-material gradation of the Arkansas-White-Red Rivers Basin, the history of bed-material sample collection, and the expected long-term trends in bed-material gradation are discussed in the following paragraphs.

## Cultural Influences on Bed-Material Gradation

123. The major cultural influences on the bed-material gradation of the streams in the Arkansas-White-Red Rivers Basin have been channel improvements (paragraphs 94-102), reservoir construction (paragraphs 103-106), and dredging. In addition, agricultural practices affect the gradation of bed material to some degree, but their influence has been lessened since the advent of the soil conservation measures of the 1930's.

124. Dredging is required to maintain navigation on the McClellan-Kerr Arkansas River Waterway, the White River, the Red River downstream from Fulton, Ark., and the Ouachita-Black Rivers Waterway downstream from Camden, Ark.[82] The Arkansas-White-Red Rivers Basin extends over five CE Districts, and the responsibility for dredging these waterways is shared among these districts as follows:

| Waterway | Responsible CE District |
|---|---|
| McClellan-Kerr Arkansas River Waterway | |
| a. Entrance channel (mouth of White River) through lower portion of Pool 13 | Little Rock* |
| b. Upper portion of Pool 13 through Newt Graham Pool (Verdigris River) | Tulsa |
| White River | Memphis |
| Red River | New Orleans |
| Ouachita-Black Rivers Waterway | Vicksburg |

* The Little Rock-Vicksburg District boundary is at Lock and Dam 4; however, Little Rock District maintains navigation on the waterway itself downstream from this structure to the confluence of the entrance channel with the Mississippi River.

Maintenance dredging records for these channels are provided in Tables E10-E13.

125. The quantities of material dredged each year cannot be directly correlated with need; fiscal and environmental constraints play an important role in the selection of dredging sites and disposal areas. Unit costs have soared in the past few years, with much of the increase attributable both to escalating operating expenses and to reduced dredging volumes. Current (1978) unit costs are as follows:

| Waterway | Cost, per cu yd |
|---|---|
| McClellan-Kerr Arkansas River Waterway | $0.89 |
| White River | 0.59 |
| Red River | 0.29 |
| Ouachita-Black Rivers Waterway | 0.61 |

126. On the McClellan-Kerr Arkansas River Waterway the current problem reaches are in the upper end of Pool 2 and in the entrance

channel, particularly during low stages of the Mississippi River. Because there are no operational locks and dams on the White River, none of the shoaling problems in this waterway can be attributed to the presence of such structures; however, there are several reaches that must be dredged on a regular basis to maintain the navigation channel. The dredging problems on the Red River Waterway will not be fully understood until the waterway becomes operational, but the most troublesome reach will probably be downstream from Lock and Dam 1 (under construction), especially near the confluence of the Red with the Ouachita-Black Waterway. Much of the dredging on the Ouachita-Black Waterway is below Jonesville Lock and Dam, the farthest downstream structure on the waterway. No doubt other troublesome reaches will develop as this waterway adjusts itself to the four-dam system that will replace the present six-dam configuration.

## History of Bed-Material Sample Collection

127. Records of the available bed-material sample collection stations in the basin were examined to determine if they met either of the following requirements:

- a. A 10-year continuous record during which five or more gradation samples were taken on at least 30 days during the period.
- b. At least two years of continuous record averaging at least five days per year on which five or more samples were taken.

Nine stations, all in the Kansas portion of the Upper Arkansas River and all operated by the USGS met either or both of the above criteria (Table E14). The locations of these stations are plotted on Figures E8 and E9. These data (published in Reference 72) were used to prepare the bed-material gradation envelopes which are presented in Figures E21-E29 (presented in same order as listed in Table E14). The envelopes were drawn by constructing pairs of curves, one connecting the highest and the other connecting the lowest "percent-finer-by-weight" values for selected sieve sizes from 0.062 mm to 64 mm for all samples taken at a

given station. Extreme points occurring on days when fewer than five samples were taken were deleted from consideration, and the next higher (or lower) value was used.

128. In addition to the USGS bed-material sample collection effort in the upper reaches of the Arkansas, several studies have been conducted in conjunction with the development of navigation and flood control projects along the lower Arkansas. Although some of these studies[78,83-88] were of a localized or short-term nature, or the resulting data are no longer valid because of changes in stream regime, the information should be of some historical value, or possibly of current value in some instances.

129. Prior to 1979, no known bed-material samples had been collected on the White River. As part of a program to investigate bed degradation on the White, the U. S. Army Engineer District, Little Rock (LRD), is now currently collecting bed-material samples. The U. S. Army Engineer District, New Orleans (NOD), has collected samples at three Red River Stations: Fulton, Alexandria, and Above Old River Outflow Channel; however, the resulting data do not meet either of the criteria in paragraph 127.

## Long-Term Trends in Bed-Material Gradation

130. Commercial dredge operators report that the bed material downstream from Pine Bluff (mile 75.0) to the mouth of the Arkansas River is fine sand. Upstream from Pine Bluff deposits of medium and coarse sand and gravel can also be found, although the percentages of material available are variable from reach to reach due to the presence of dams and previously dredged sites. Observations by the U. S. Army Engineer District, Tulsa, indicate that the bed-material gradation is generally 80 percent sand and 20 percent gravel upstream from Ft. Smith, Arkansas (mile 300.0), to Hutchinson, Kansas (mile 800.0), although again wide variations exist in material availability due to structures and prior dredging.

131. Samples taken on the upstream ends of the Arkansas main-stem

reservoirs indicate that there is a coarsening of the bed material taking place; however, within the central portion of the large reservoirs, there is an increase of fines settling out of suspension. According to U. S. Army Engineer Division, Southwestern (SWD), these trends are expected to continue. SWD has also predicted an overall reduction in dredging required to maintain the main-stem navigation channel until around the year 2000, after which gradual increases in dredging volumes are expected.

132. The bed-material sample collection program initiated by LRD on the White River in 1979 has not been operational long enough to provide a basis for predicting long-term trends. Commercial dredge operators indicate that equal amounts of sand and gravel are generally removed from the bed of the White River at Clarendon, Arkansas (mile 100.1), and at Newport, Arkansas (mile 257.6).

133. Limited bed-material sampling has been conducted on the Red River by NOD at three stations (paragraph 129). The available data were used to prepare representative particle-size distributions for each station. The procedure for construction of a representative distribution is to first determine the percent of the total weight retained on each sieve for all samples, sum the values for each sieve size, and then divide each sum by the number of samples. Using the resulting average for each sieve size, representative distributions were then constructed for each station. A "typical" value for the fraction of medium and fine sand and silt present in the bed material passing each station was then determined from the distribution curves. The resulting values are as follows:

| Station | River Mile | Period of Record | Number of Samples | Percentage Medium Sand | | |
|---|---|---|---|---|---|---|
| | | | | Medium Sand | Fine Sand | Silt |
| Fulton | 401.8 | 25 February 1975-11 November 1977 | 45 | 2 | 41 | 57 |
| Alexandria | 104.9 | 8 April 1971-9 September 1976 | 54 | 3 | 80 | 17 |
| Above Old River Outflow Channel | 13.1 | 24 February 1971-20 October 1976 | 80 | 7 | 56 | 37 |

Thus, through the lower 400-mile reach of the Red River, the bed material is more than 90 percent fine sand and silt, although the percentage of each component varies. Dredging in the vicinity of mile 65 during 1977-1978 indicated that the removed material was 76 percent fine sand and 24 percent silt.

134. Lock and Dam 1 (farthest downstream structure) on the Red River Waterway is now under construction. The remainder of the dams are scheduled to be completed within the next several years. All of the dams will be operated on a run-of-the-river basis, permitting unencumbered flow of suspended sediment and bed material. NOD expects no changes in the particle-size distribution of the bed material as a result of this construction. Additional dredging in the reach immediately downstream from Lock and Dam 1 will probably be required to maintain the project channel. This reach also receives the sediment inflow from the entrance channel of the Ouachita-Black Waterway. The streambed gradient of the newly constructed Red River Waterway is expected to undergo some adjustment as a result of the new locks and dams and its slightly shortened course (due to the cutoffs that are an integral part of the Waterway project).

## PART V: SUMMARY

135. The Arkansas River is the major suspended-sediment contributor to the Mississippi main stem below Cairo. The hydraulic and sediment regimes of the Arkansas have been significantly altered in recent years because of improved land-use practices, channelization, and the construction of sediment retention structures. Prior to the construction of these impoundments, the annual suspended-sediment load passing Little Rock was in excess of 100 million tons (based on 1939-1953 data). The load passing this station is generally regarded as reflecting the contribution of the Arkansas to the Mississippi main stem. Closure of several upstream structures has reduced the sediment load at Little Rock to 12 percent of its natural value, probably reflecting a similar decrease in the contribution of the Arkansas to the Mississippi main stem.

136. Annual sediment yields in the White River drainage are less than 480 tons per square mile; consequently, the suspended-sediment loads found in the streams of this basin are very low. The average annual suspended sediment contribution of the White River to the Mississippi River's load is estimated to be less than 4 million tons.

137. The suspended-sediment load of the Red River upstream from Denison Dam is effectively trapped when the load reaches the reservoir; practically none of this load is passed into the Lower Red River. Downstream from Denison Dam the average load of the Red increases again, reaching a maximum of 40 million tons per year at its mouth. The stabilization of banks in the reach downstream from Shreveport (part of the ongoing Red River Waterway Project) will reduce the supply of sediment available for transport; however, until the complete river system above Shreveport is stabilized, essentially the same amount of sediment will have to be transported through the lower Red because of the large volume of material that will continue to pass Shreveport. There will be little modification of the current sediment regime as a result of the navigation dam construction downstream from Shreveport; proposed operational plans will require that the gates be fully open at flows above half-bankfull when most of the sediment transport occurs.

138. Commercial dredge operators report that the bed material downstream from Pine Bluff (mile 75.0) to the mouth of the Arkansas River is fine sand. Upstream from Pine Bluff deposits of medium and coarse sand and gravel can also be found, although the percentages of material available are variable from reach to reach due to the presence of dams and previously dredged sites. Observations by the U. S. Army Engineer District, Tulsa, indicate that the bed-material gradation is generally 80 percent sand and 20 percent gravel upstream from Ft. Smith, Arkansas (mile 300.0), to Hutchinson, Kansas (mile 800.0), although again wide variations exist in material availability due to structures and prior dredging.

139. Samples taken on the upstream ends of the Arkansas main-stem reservoirs indicate that there is a coarsening of the bed material taking place; however, within the central portion of the large reservoirs, there is an increase of fines settling out of suspension. According to SWD, these trends are expected to continue. SWD has also predicted an overall reduction in dredging required to maintain the main-stem navigation channel until around the year 2000, after which gradual increases in dredging volumes are expected.

140. The bed-material sample collection program initiated by LRD on the White River in 1979 has not been operational long enough to provide a basis for predicting long-term trends. Commercial dredge operators indicate that equal amounts of sand and gravel are generally removed from the bed of the White River at Clarendon, Arkansas (mile 100.1), and at Newport, Arkansas (mile 257.6).

141. Limited bed-material sampling has been conducted on the Red River by NOD at three stations (paragraph 129). Examination of the data resulting from samples collected at these stations indicates that through the lower 400 mile reach of the Red, the bed material is more than 90 percent fine sand and silt, although the percentage of each component varies.

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Table E1

Subbasins - Arkansas-White-Red Rivers Basin

| Subbasin | Area square miles | Elevation, ft Minimum | Elevation, ft Maximum | Average Annual Precipitation in. |
|---|---|---|---|---|
| Cimarron-North Canadian-Canadian Rivers | 63,675 | 287 | 7,530 | 25 |
| Lower Arkansas River | 49,011 | 145 | 2,753 | 43 |
| Lower Red River | 36,350 | 35 | 2,600 | 49 |
| Ouachita River | 19,995 | 55 | 1,390 | 52 |
| Upper Arkansas River | 48,165 | 458 | 14,414 | 21 |
| Upper Red River | 39,734 | 669 | 4,800 | 26 |
| White River | 25,070 | 101 | 2,370 | 45 |
| Total | 282,000 | | | |

Table E2

1977 Freight and Passenger Traffic in the

Arkansas-White-Red Rivers Basin*

| Stream | Reach | Freight Traffic short tons | No. of Passengers |
|---|---|---|---|
| McClellan-Kerr Arkansas River Navigation System | Mouth of White River to Catoosa, Okla. | 9,145,958 | 1,431 |
| Ouachita and Black Rivers | Mouth of Black River to Camden, Ark. (336 miles) | 1,041,580 | 10,348 |
| Red River | Confluence of Old, Red, and Atchafalaya Rivers to Fulton, Ark. | 1,404,432 | -- |
| White River | Junction with Arkansas Post Canal to Batesville, Ark. | 660,982 | 47 |

* *Source: Reference 37.*

Table E3

Selected Cities in the Arkansas-White-Red Rivers Basin and Dates Settled

| City | Date |
|---|---|
| Monroe, La. | 1790 |
| Shreveport, La. | 1803 |
| Alexandria, La. | 1810 |
| Little Rock, Ark. | 1812 |
| Fort Smith, Ark. | 1817 |
| Pine Bluff, Ark. | 1819 |
| Tulsa, Okla. | 1836* |
| Pueblo, Colo. | 1842 |
| Wichita, Kans. | 1870 |
| Muskogee, Okla. | 1872 |
| Amarillo, Tex. | 1887 |
| Oklahoma City, Okla. | 1889 |

* Date settled by Creek Indians from Georgia. White settlers arrived in 1882.

Table E4

Population in the Arkansas-White-Red Rivers Basin

1900-1970

| Year | Urban Population | Rural Population | Total Population | Reference |
|---|---|---|---|---|
| 1900 | | | 4,636,000* | 40 |
| 1910 | | | 6,174,000* | 40 |
| 1930 | | | 7,100,000 | 1 |
| 1940 | 2,438,000 | 4,775,000 | 7,213,000 | 1 |
| 1950 | 3,170,000 | 4,002,000 | 7,172,000 | 1 |
| 1960 | | | 7,916,784 | 6,7 |
| 1970 | | | 8,475,503 | 6,7 |

* In towns and cities having populations of 2500 or greater.

Table E5

Land-Use Data - Arkansas-White-Red Rivers Basin

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest* | Other Land* | Total Land Area |
| | | 1860 | | | |
| Arkansas | 1,800,452 | 6,890,559 | 21,977,861 | | 30,668,872 |
| Indian Territory* | | | 44,661,245 | | 44,661,245 |
| Kansas Territory | 156,146 | 528,716 | 45,012,791 | | 45,697,653 |
| Louisiana | 1,046,027 | 2,546,943 | 7,636,506 | | 11,229,476 |
| Missouri | 1,226,885 | 2,698,131 | 4,713,468 | | 8,638,484 |
| New Mexico Territory | 22,107 | 187,441 | 11,404,114 | | 11,613,662 |
| Texas | 441,355 | 3,778,426 | 23,750,827 | | 27,970,608 |
| Total | 4,692,972 | 16,630,216 | 159,156,812 | | 180,480,000 |
| | (2.60%) | (9.21%) | (88.19%) | | |

(Continued)

* Forest and other land categories were not surveyed separately in the 1860 census (Reference 57), and land use was not surveyed in the Indian Territory.

(Sheet 1 of 4)

Table E5 (Continued)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1910 | | | |
| Arkansas | 7,349,197 | 793,976 | 8,106,266 | 14,419,433 | 30,668,872 |
| Colorado | 906,431 | 2,772,897 | 349,582 | 14,243,577 | 18,272,487 |
| Kansas | 14,186,288 | 6,735,543 | 514,911 | 5,988,424 | 27,425,166 |
| Louisiana | 2,281,939 | 204,999 | 2,500,876 | 6,241,662 | 11,229,476 |
| Missouri | 2,919,399 | 142,446 | 2,161,361 | 3,415,278 | 8,638,484 |
| New Mexico Territory | 295,252 | 2,760,918 | 52,668 | 8,504,824 | 11,613,662 |
| Oklahoma | 17,656,125 | 7,785,310 | 3,590,223 | 15,629,587 | 44,661,245 |
| Texas | 6,019,474 | 11,282,141 | 2,221,834 | 8,447,159 | 27,970,608 |
| Total | 51,614,105 | 32,478,230 | 19,497,721 | 76,889,944 | 180,480,000 |
| | (28.60%) | (18.00%) | (10.80%) | (42.60%) | |

(Continued)

(Sheet 2 of 4)

Table E5 (Continued)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1935 | | | |
| Arkansas | 5,572,623 | 3,134,188 | 6,048,664 | 15,913,397 | 30,668,872 |
| Colorado | 1,771,193 | 7,878,594 | 563,685 | 8,059,015 | 18,272,487 |
| Kansas | 12,388,712 | 10,899,638 | 495,411 | 3,641,405 | 27,425,166 |
| Louisiana | 1,935,039 | 765,254 | 1,856,233 | 6,672,950 | 11,229,476 |
| Missouri | 1,536,976 | 1,603,351 | 2,268,546 | 3,229,611 | 8,638,484 |
| New Mexico | 753,066 | 7,609,886 | 384,622 | 2,866,088 | 11,613,662 |
| Oklahoma | 15,318,085 | 13,777,377 | 4,875,676 | 10,690,107 | 44,661,245 |
| Texas | 8,535,362 | 13,426,753 | 1,874,981 | 4,133,512 | 27,970,608 |
| Total | 47,811,056 | 59,095,041 | 18,367,818 | 55,206,085 | 180,480,000 |
| | (26.49%) | (32.74%) | (10.18%) | (30.59%) | |

(Continued)

(Sheet 3 of 4)

Table E5 (Concluded)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1967 | | | |
| Arkansas | 5,988,916 | 4,656,686 | 15,233,631 | 4,789,639 | 30,668,872 |
| Colorado | 3,133,161 | 10,505,493 | 1,528,484 | 3,105,349 | 18,272,487 |
| Kansas | 15,087,723 | 9,416,727 | 307,991 | 2,612,725 | 27,425,166 |
| Louisiana | 1,652,849 | 1,246,158 | 7,234,084 | 1,096,385 | 11,229,476 |
| Missouri | 1,493,005 | 1,469,563 | 4,220,244 | 1,455,672 | 8,638,484 |
| New Mexico | 733,591 | 8,252,776 | 2,102,974 | 524,321 | 11,613,662 |
| Oklahoma | 12,733,166 | 19,357,764 | 8,402,120 | 4,168,195 | 44,661,245 |
| Texas | 8,586,178 | 15,663,469 | 2,173,171 | 1,547,790 | 27,970,608 |
| Total | 49,408,589 | 70,568,636 | 41,202,699 | 19,300,076 | 180,480,000 |
| | (27.38%) | (39.10%) | (22.83%) | (10.69%) | |

(Sheet 4 of 4)

Table E6

Estimated Annual Sediment Yield of Subbasins in the Arkansas-White-Red Rivers Basin

| Subbasin | Area square miles | Unit Annual Sediment Yield tons/square mile | Annual Sediment Yield, tons |
|---|---|---|---|
| Cimarron-North Canadian-Canadian Rivers | 63,675 | 1596 | 101,625,300 |
| Lower Arkansas River | 49,011 | 523 | 25,632,753 |
| Lower Red River | 36,350 | 1393 | 50,635,550 |
| Ouachita River | 19,995 | 972 | 19,435,140 |
| Upper Arkansas River | 48,165 | 1234 | 59,435,610 |
| Upper Red River | 39,734 | 2096 | 83,282,464 |
| White River | 25,070 | 240 | 6,016,800 |
| Total | 282,000 | 1227 | 346,063,617 |

* Subbasin estimates were computed on an areal basis using unit sediment yields from Reference 1. These estimates are cumulative sums and do not reflect measures that have been taken to minimize stream sediment loads (i.e., impoundments, dikes, soil conservation practices, etc.); nor do the estimates account for sediment originating in upstream areas outside the subbasin that eventually must pass through the subbasin. Thus, the estimates provided in this table more properly reflect the potential areal yields of the subbasins rather than actual yields.

Table E7

Dams - Arkansas-White-Red Rivers Basin*

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Contributing Drainage Area $mi^2$ Current** (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cimarron-North Canadian-Canadian Rivers | Canadian River | Eufala | | 1964 | 47,552 | 13,693 | 3,848,000 | Jun 1969 | 3,798,400 | 9,311 | 12,611,200 | CE |
| | | Sanford | | 1965 | | | 1,408,000 | | | | | Canadian River Municipal Water Authority (constructed by BR) |
| | | Ute | | 1963 | | | 109,600 | | | | | New Mexico Instate Stream |
| | | Conchas | | 1939 | 7,049 | 6,976 | 709,100 | Oct 1970 | 529,000 | 3,160 | 4,204,100 | CE |
| | Cimarron Creek | Eagle Nest | | 1918 | | | 78,800 | | | | | CS Ranch Co. |
| | Hog Creek and Little River | Norman (Lake Thunderbird) | | 1965 | | | 196,000 | | | | | Central Oklahoma Master Conservancy District (constructed by BR) |
| | North Canadian River | Canton | | 1948 | 12,483 | 6,081 | 386,000 | Sep 1966 | 383,300 | 383 | 462,200 | CE |
| | | Optima | | 1978 | | | 359,000 | | | | | CE |

(Continued)

* With design storge capacities >75,000 acre-ft.
** Current (1977) contributing drainage areas include many small catchment structures whose retention efficiencies have not been inventoried.
† CE - Corps of Engineers, BR - Bureau of Reclamation, GRDA - Grand River Dam Authority.

(Sheet 1 of 10)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cimarron-North* Canadian-Canadian-Rivers (Cont'd) | Tributary, Bluff Creek | Lake Hefner | | 1945 | | | 75,000 | | | | | City of Oklahoma City, Okla. |
| | Tributary, East Elm Creek | City of Oklahoma City (Stanley Draper Lake) | | 1963 | | | 100,000 | | | | | City of Oklahoma City, Okla. |
| | Wolf Creek | Fort Supply | | 1971 | 1,735 | 1,485 | 102,000 | Dec 1969 | | 91 | 109,900 | CE |
| Lower Arkansas River | Arkansas River | Dam No. 2 | | 1967 | 160,475 | | 110,000 | | | | | CE |
| | | Murray Lock and Dam | 125.4 | 1969 | | | 108,500 | | | | | CE |
| | | Dardanelle Lock and Dam | 205.5 | 1969 | 153,703 | 11,333 | 486,200 | Apr 1968 | | 3,638 | 6,346,500 | CE |
| | | Ozark Lock and Dam | 256.8 | 1969 | | | 148,000 | | | | | CE |
| | | Robert S. Kerr Lock and Dam | 336.2 | 1970 | | | 493,600 | | | | | CE |
| | | Webbers Falls Lock and Dam | 368.9 | 1970 | | | 165,200 | | | | | CE |
| | Big Maumelle River | Lake Maumelle | | 1957 | | | 200,000 | | | | | City of Little Rock, Ark. |
| | Candy Creek | Candy | | Under construction | | | 75,000 | | | | | CE |

(Continued)

(Sheet 2 of 10)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area mi2 Natural | Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Arkansas River (Cont'd) | Caney River | Hulah | 96.2 | 1951 | 732 | 712 | 278,000 | | | | | CE |
| | Cottonwood River | Marion | | 1968 | | | 146,500 | | | | | CE |
| | Elk River | Elk City | | 1966 | | | 291,000 | Jun 1958 | | 305 | 294,100 | CE |
| | Fall River | Fall | | 1949 | | | 259,000 | | | | | CE |
| | Fourche La Fave River | Nimrod | | 1942 | 680 | 652 | 336,000 | Apr 1950 | | | | CE |
| | Grand (Neosho) River | Fort Gibson | 7.7 | 1965 | 12,492 | | 1,284,400 | | | | | CE |
| | | Markham Ferry (Lake Hudson) | 43.3 | 1964 | 11,534 | | 444,500 | | | | | GRDA |
| | | Pensacola (Lake O' The Cherokees) | 77.0 | 1940 | 10,298 | | 2,197,000 | | | | | GRDA |
| | | John Redmond | | 1964 | | | 644,600 | | | | | CE |
| | | Council Grove | | 1964 | | | 114,000 | | | | | CE |
| | Hominy Creek | Skiatook | | Under construction | | | 514,000 | | | | | CE |
| | Illinois River | Tenkiller Ferry | 12.2 | 1953 | 1,610 | | 1,230,800 | | | | | CE |
| | Little Caney River | Copan | | Under construction | | | 228,000 | | | | | CE |

(Continued)

(Sheet 3 of 10)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Arkansas River (Cont'd) | Petit Jean River | Blue Mountain | | 1947 | | | 258,000 | | | | | CE |
| | Poteau River | Wister | | 1940 | 993 | 957 | 430,000 | Jul 1972 | 427,900 | 49 | 70,800 | CE |
| | Spavinaw Creek | City of Tulsa (Lake Eucha) | | 1922 | | | 79,600 | | | | | City of Tulsa, Okla. |
| | Verdigris River | Oolgah | 89.7 | 1963 | 4,339 | | 1,519,000 | | | | | CE |
| | | Toronto | | 1960 | 730 | 714 | 195,300 | May 1966 | 192,000 | 521 | 657,600 | CE |
| | Walnut Creek | El Dorado | | Under construction | | | 236,000 | | | | | CE |
| Lower Red River | Bayou Bodcau (Bodcau Creek) | Bayou Bodcau | 62.3 | 1949 | 656 | 613 | 357,300 | Apr 1972 | 967,900 | | | CE |
| | | Percy Cobb (Lake Erling) | | 1965 | | | 140,000 | | | | | International Paper Co. |
| | Bayou Bourbeux | Allen and Chilvary (Clear Lake and Black Lake) | | 1934 | | | 280,000 | | | | | State of Louisiana |
| | Bayou Rigolette | Lake Iatt | | 1957 | 242 | | 118,000 | | | | | State of Louisiana |
| | Big Cypress Creek | Lake Cypress Springs | | 1971 | | | 125,100 | | | | | TWDB and Franklin Co. Water District |

(Continued)

(Sheet 4 of 10)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Contributing Drainage Area $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Red River (Cont'd) | Black Bayou | Black Bayou | | 1955 | 231 | | 123,000 | | | | | State of Louisiana |
| | Cossatot River | Gillham | | 1976 | | | 222,000 | | | | | CE |
| | Cross Bayou | Cross Lake | | 1925 | 256 | | 79,000 | | | | | City of Shreveport, La. |
| | Cypress Bayou (Cypress Creek) (tributary to Cross Bayou) | Caddo Lake | | 1971 | | | 755,000 | | | | | Caddo Levee District |
| | | Ferrells Bridge (Lake O' The Pines) | 81.2 | 1958 | 1,100 | 790 | 842,100 | Mar 1974 | | | | CE |
| | Cypress Bayou (tributary to Bayou Pierre) | Wallace Lake | 67.4 | 1946 | 260 | 246 | 96,100 | Apr 1972 | | | | CE |
| | Cypress Bayou (tributary to Red Chute Bayou) | Cypress Black Bayou Site No. 1 | | 1974 | 155 | | 77,000 | | | | | State of Louisiana |
| | Jackfork Creek | Clayton | | Under construction | | | 431,000 | | | | | CE |
| | Kiamichi River | Hugo | | 1970 | | | 967,000 | | | | | CE |
| | Little River | Millwood | | 1966 | | | 2,567,900 | | | | | CE |
| | | Pine Creek | | 1969 | | | 466,000 | | | | | CE |

(Continued)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Contributing Drainage Area $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Red River (Cont'd) | Loggy Bayou | Lake Bistineau | | 1941 | 1,410 | | 318,000 | | | | | State of Louisiana |
| | Mountain Fork | Broken Bow | | 1969 | | | 1,369,000 | | | | | CE |
| | North Boggy Creek | Atoka | | 1964 | | | 191,000 | | | | | City of Oklahoma City, Okla. |
| | Rolling Fork | DeQueen | | 1977 | | | 136,000 | | | | | CE |
| | Saline Bayou | Saline Lake | | 1959 | 420 | | 122,000 | | | | | State of Louisiana |
| | Saline River | Dierks | | 1976 | | | 97,000 | | | | | CE |
| | Sandy Creek | Pat Mayse | | 1968 | | | 175,000 | | | | | CE |
| | South Sulphur River | Cooper | 23.7 | Under construction | 476 | | 441,400 | | | | | CE |
| | Sulphur River | Texarkana | 44.5 | 1956 | 3,400 | 3,213 | 2,654,300 | Jul 1970 | | | | CE |
| Ouachita River | Bayou D'Arbonne | Bayou D'Arbonne | | 1961 | 1,585 | | 240,000 | | | | | State of Louisiana |
| | | Lake Claiborne | | 1966 | 133 | | 200,000 | | | | | State of Louisiana |
| | Black River | Jonesville Lock and Dam | | 1972 | | | 149,300 | | | | | CE |
| | Caddo River | DeGray | 7.9 | 1972 | 453 | | 781,900 | | | | | CE |
| | Larto Bayou | Larto Lake | | 1950 | | | 126,000 | | | | | State of Louisiana |
| | Little River and Diversion Channel | Catahoula Lake (two dams) | | 1972 | 2,672 | | 132,000 | | | | | State of Louisiana |

(Continued)

(Sheet 6 of 10)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Contributing Drainage Area $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ouachita River (Cont'd) | Little Missouri River | Narrows (Lake Greeson) | 105.5 | 1950 | 237 | | 407,900 | | | | | CE |
| | Ouachita River | Columbia Lock and Dam | | 1970 | | | 156,800 | | | | | CE |
| | | Lock and Dam No. 8 | | 1911 | | | 85,000 | | | | | CE |
| | | Remmel (Lake Hamilton) | | 1924 | 1,421 | | 156,300 | May 1950 | 153,300 | | | Arkansas Power and Light Co. |
| | | Blakely Mountain (Lake Ouachita) | 430.4 | 1955 | 1,105 | | 2,768,500 | | | | | CE |
| Upper Arkansas River | Adobe Creek | Adobe Creek | | 1969 | | | 88,300 | | | | | Fort Lyon Canal Co. |
| | Arkansas River | Keystone | 538.8 | 1964 | 74,506 | 17,136 | 1,879,000 | Sep 1969 | 1,836,500 | 8,054 | 10,453,800 | CE |
| | | Kaw | | 1976 | | | 1,348,000 | | | | | CE |
| | | John Martin | | 1951 | 18,915 | 18,102 | 702,800 | Mar 1972 | 621,300 | -718 (Negative values due to "inward erosion" since Aug 1968 survey) | -1,176,[illegible]00 | CE |
| | | Pueblo | | 1975 | | | 357,000 | | | | | BR |
| | Arkansas River (Lake Fork) | Sugar Loaf (Turquoise Lake) | | 1968 | | | 129,000 | | | | | BR |
| | Arkansas River (Salt Fork) | Great Salt Plains | | 1941 | 3,200 | 3,156 | 280,200 | Mar 1971 | 217,400 | 903 | 1,559,100 | CE |

(Continued)

(Sheet 7 of 10)

Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$: Natural | Contributing Drainage Area $mi^2$: Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow: acre-ft | Average Annual Sediment Inflow: tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Arkansas River (Cont'd) | Ninnescah River (North Fork) | Cheney | | 1965 | | | 248,000 | | | | | City of Wichita, Kans. (constructed by BR) |
| | Purgatoire River | Trinidad | | 1978 | | | 240,000 | | | | | CE |
| | Tributary, Monument Creek | North Calamont | | 1959 | | | 154,000 | | | | | City of Colorado Springs, Colo. |
| | Tributary, Purgatoire River | Bent and Prowers No. 2 | | 1914 | | | 156,700 | | | | | Bent and Prowers Ir-.igation District |
| Upper Red River | Beaver Creek | Waurika | | 1977 | | | 343,000 | | | | | CE |
| | Holliday Creek | Lake Wichita | | 1901 | | | 92,000 | | | | | City of Wichita Falls, Tex. |
| | Little Wichita River | Wichita Falls | | 1966 | | | 460,000 | | | | | City of Wichita Falls, Tex. |
| | Little Wichita River (North Fork) | Kickapoo | | 1945 | | | 220,000 | | | | | City of Wichita Falls, Tex. |
| | Otter Creek | Mountain Park (Tom Steed Reservoir) | | 1975 | | | 116,000 | | | | | BR |
| | Pond Creek | Fort Cobb | | 1959 | | | 144,000 | | | | | Fort Cobb Reservoir Master Conservancy District (constructed by BR) |

(Continued)

(Sheet 8 of 10)

AD-A111 263 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/8
CHARACTERIZATION OF THE SUSPENDED-SEDIMENT REGIME AND BED-MATER--ETC(U)
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Table E7 (Continued)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Contributing Drainage Area $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Upper Red River (Cont'd) | Red River | Denison (Lake Texoma) | | 1944 | 39,719 | 28,925 | 5,382,000 | Mar 1962 | | 20,508 | 27,912,600 | CE |
| | Red River (North Fork) | Altus | | 1945 | 2,515 | 2,104 | 154,000 | Apr 1967 | | 760 | 1,237,200 | Constructed by BR |
| | Red River (Salt Fork) | Greenbelt | | 1967 | | | 78,500 | | | | | Greenbelt MIWA |
| | Rock Creek | Arbuckle (Lake of the Arbuckles) | | 1966 | | | 109,000 | | | | | Arbuckle Master Conservancy District (constructed by BR) |
| | Tributary, Andarche Creek | State of Oklahoma (Lake Murray) | | 1937 | | | 153,200 | | | | | State of Oklahoma |
| | Washita River | Foss | | 1961 | | | 437,000 | | | | | Foss Reservoir Master Conservancy District (constructed by BR) |
| | Wichita River | Lake Kemp | 126.7 | 1972* | 2,086 | 2,067 | 619,100 | Sep 1958 | 619,100 | | | Wichita County Water Improvement District No. 2 |
| White River | Black River | Clearwater | 257.4 | 1948 | 898 | | 413,000 | | | | | CE |
| | Little Red River | Greers Ferry | 79.0 | 1962 | 1,146 | | 2,844,000 | | | | | CE |

(Continued)

* Initially closed 1923; rehabilitated 1972 by CE with a spillway elevation 7 ft higher than original design.

(Sheet 9 of 10)

Table E7 (Concluded)

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area $mi^2$ Natural | Contributing Drainage Area $mi^2$ Current (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | Average Annual Sediment Inflow tons | Responsible Agency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| White River (Cont'd) | White River | Bull Shoals | 418.6 | 1952 | 6,036 | | 5,408,000 | | | | | CE |
| | | Table Rock | 528.8 | 1958 | 4,020 | | 3,462,000 | | | | | CE |
| | | Beaver | 609.0 | 1966 | 1,186 | | 1,952,000 | | | | | CE |
| | White River (North Fork) | Norfork | 4.8 | 1945 | 1,806 | 1,772 | 1,983,000 | May 1950 | 1,560,500 | | | CE |

(Sheet 10 of 10)

Table E8

Summary of Pre-1900 and 1930-1931 Data for Suspended-Sediment Sample Collection Stations in the Arkansas-White-Red Rivers Basin*

| Station | River Mile | Observation Period: Dates | Observation Period: No. of Days Sampled | Discharge, acre-ft: Maximum | Discharge, acre-ft: Mean | Discharge, acre-ft: Minimum | Suspended-Sediment Load tons/day: Maximum | Suspended-Sediment Load tons/day: Mean | Suspended-Sediment Load tons/day: Minimum |
|---|---|---|---|---|---|---|---|---|---|
| Arkansas River at Pine Bluff, Ark. | 110 | 20 Feb 1879-8 Jul 1879 | 124 | 126,456 | 29,462 | 7,581 | 343,686 | 20,589 | 544 |
| Arkansas River at Ozark, Ark. | 321 | 22 Oct 1930-2 Sep 1931 | 94 | 143,566 | 43,476 | 6,744 | 621,691 | 102,557 | 1,642 |
| Arkansas River at Tulsa, Okla. | 530 | 18 Oct 1930-8 Sep 1931 | 73 | 92,907 | 7,277 | 238 | 924,480 | 41,386 | 216 |
| Black River at Black Rock, Ark. | 68 | 13 Apr 1931-26 Jun 1931 | 57 | 40,662 | 16,469 | 8,073 | 25,099 | 2,851 | 1,080 |
| Cimmaron River at Guthrie, Okla. | 111 | 15 Oct 1930-8 Sep 1931 | 68 | 12,159 | 1,609 | 149 | 179,366 | 17,582 | 259 |
| Grand (Neosho) River at Wagoner, Okla. | 13 | 24 Oct 1930 7 Sep 1931 | 72 | 62,917 | 10,037 | 2,063 | 100,786 | 4,406 | 130 |
| Little River at Idabel, Okla. | -- | 7 Nov 1930-15 Jan 1931 | 21 | 11,623 | 1,404 | 149 | 1,425 | 194 | 11 |
| Little River at Horatio, Okla. | -- | 21 Jun 1931-28 Sep 1931 | 85 | 30,546 | 6,613 | 151 | 3,326 | 475 | 9 |

(Continued)

* Data taken from References 66 and 67.

Table E8 (Concluded)

| Station | River Mile | Observation Period: Dates | Observation Period: No. of Days Sampled | Discharge, acre-ft: Maximum | Discharge, acre-ft: Mean | Discharge, acre-ft: Minimum | Suspended-Sediment Load tons/day: Maximum | Suspended-Sediment Load tons/day: Mean | Suspended-Sediment Load tons/day: Minimum |
|---|---|---|---|---|---|---|---|---|---|
| Little River at Wilton, Ark. | -- -- | 7 Sep 1930– 1 Nov 1930 | 19 | 4,443 | 662 | 16 | 1,270 | 130 | 2 |
| Red River at Alexandria, La. | 111 | 24 Feb 1879– 1 Jul 1879 | 110 | 98,534 | 50,742 | 16,451 | 83,233 | 26,996 | 4,692 |
| | 118 | 23 Sep 1930– 19 Sep 1931 | 155 | 123,572 | 45,325 | 3,491 | 856,656 | 96,638 | 605 |
| Red River at Denison, Tex. | 768 | 9 Sep 1930– 30 Sep 1931 | 160 | 77,357 | 7,545 | 298 | 781,920 | 38,578 | 86 |
| South Canadian River at Calvin, Okla. | 105 | 30 Oct 1930– 2 Sep 1931 | 71 | 8,727 | 1,438 | 18 | 149,299 | 11,275 | 13 |
| Sulphur River at Darden, Tex. | -- | 10 Sep 1930– 24 Sep 1931 | 120 | 15,471 | 2,646 | 1 | 18,706 | 2,333 | 0 |
| Verdigris River at Okay, Okla. | 4 | 28 Oct 1930– 7 Sep 1931 | 74 | 45,621 | 5,808 | 258 | 263,174 | 8,899 | 39 |
| Washita River at Durwood, Okla. | -- | 8 Sep 1930– 23 Sep 1931 | 109 | 17,098 | 2,043 | 218 | 278,208 | 12,269 | 39 |
| White River at DeValls Bluff, Ark. | 124 | 6 Feb 1931– 30 May 1931 | 36 | 95,605 | 61,479 | 13,250 | 43,070 | 9,590 | 734 |
| White River at Clarendon, Ark. | 134 | 19 Jan 1879– 26 Jan 1879 | 135 | 77,091 | 38,680 | 11,826 | 3,447 | 1,888 | 458 |

Table E9

Suspended-Sediment Sample Collection Stations - Arkansas-White-Red Rivers Basin

| Subbasin | Stream | Station | River Mile | Period of Record,* Water Years | Contributing Drainage Area Above Station** $mi^2$ | Responsible Agency† |
|---|---|---|---|---|---|---|
| Lower Arkansas River | Arkansas River | Little Rock, Ark. | 141.5 | 1941 | 158,030 | CE/GS |
| | | Dardanelle, Ark. | 219.5 | 1964 | 153,670 | CE/GS |
| | | Near Van Buren, Ark. | 308.9 | 1944 | 150,547 | CE/GS |
| Lower Red River | Red River | Alexandria, La. | 104.9 | 1952 | 67,000 | CE |
| Upper Arkansas River | Arkansas River | Arkansas City, Kans. | 701.4 | 1962-1975 | 43,713 | GS |
| | | Near Hutchinson, Kans. | 800.3 | 1961-1969 | 38,910 | GS |
| | | Kinsley, Kans. | 920.3 | 1961-1975 | 31,066 | GS |

(Continued)

* Water years of complete record inclusive. Years standing alone indicate the beginning of a period of record of a currently operating station.

** Natural flows affected by irrigation development and by storage in an undetermined number of large and small reservoirs.

† CE - Corps of Engineers, GS - U. S. Geological Survey.

Table E9 (Concluded)

| Subbasin | Stream | Station | River Mile | Period of Record Water Years | Contributing Drainage Area Above Station $mi^2$ | Responsible Agency |
|---|---|---|---|---|---|---|
| Upper Arkansas River | Arkansas River | Las Animas, Colo. | 1176.6 | 1963 | 14,417 | CE |
| | Purgatoire River | Las Animas, Colo. | 4.5 | 1963 | 3,503 | CE |
| | Walnut Creek | Albert, Kans. | 43.0 | 1962-1975 | 1,410 | GS |
| | Walnut River | Winfield, Kans. | 24.8 | 1964-1975 | 1,872 | GS |

Table E10

Maintenance Dredging on the McClellan-Kerr Arkansas River Waterway*

| Calendar Year | Quantity of Material Dredged, cu yd: Tulsa District | Quantity of Material Dredged, cu yd: Little Rock |
|---|---|---|
| 1969 | 0 | 1,004,000 |
| 1970 | 0 | 1,726,000 |
| 1971 | 2,114,000 | 1,440,000 |
| 1972 | 4,410,000 | 2,697,000 |
| 1973 | 5,316,000 | 4,216,000 |
| 1974 | 7,775,000 | 4,088,000 |
| 1975 | 2,101,000 | 1,424,000 |
| 1976 | 541,000 | 1,876,000 |
| 1977 | 259,000 | 1,740,000 |
| 1978 | 193,000 | 1,157,000 |

* Reference 82 and file information provided by U. S. Army Engineer Division, Southwestern, Dallas, Tex.

Table E11

Maintenance Dredging on the White River*

| Period | Quantity of Material Dredged, cu yd |
|---|---|
| 29 Aug 1964- 6 Nov 1964 | 266,120 |
| 9 Aug 1965-26 Nov 1965 | 341,536 |
| 9 Oct 1966-17 Nov 1966 | 324,459 |
| 9 Aug 1967-19 Sep 1967 | 345,682 |
| 30 Sep 1968-14 Nov 1968 | 354,076 |
| 29 Jul 1969-23 Oct 1969 | 761,643 |
| 19 Aug 1970- 9 Oct 1970 | 368,099 |
| 13 Sep 1971-10 Nov 1971 | 432,830 |
| 19 Aug 1972- 3 Nov 1972 | 725,445 |
| 13 Nov 1973- 7 Jan 1974 | 263,733 |
| 14 Jul 1974-20 Oct 1974 | 1,038,111 |
| 9 Aug 1975-12 Nov 1975 | 894,482 |
| 11 Oct 1976-12 Dec 1976 | 687,870 |
| 19 Nov 1977-19 Dec 1977 | 94,514 |
| 29 Jun 1978- 8 Nov 1978 | 883,895 |

* File information furnished by U. S. Army Engineer District, Memphis, Memphis, Tenn.

Table E12

Maintenance Dredging on the Red River*

| Fiscal Year | Quantity of Material Dredged, cu yd |
|---|---|
| 1968 | 63,319 |
| 1969 | 0 |
| 1970 | 0 |
| 1971 | 0 |
| 1972 | 23,044 |
| 1973 | 23,912 |
| 1974 | 0 |
| 1975 | 0 |
| 1976 | 0 |
| 1976-T | 190,792 |
| Calendar Year | |
| 1977 | 1,012,168 |
| 1978 | 1,046,860 |

* File information provided by U. S. Army Engineer Division, Lower Mississippi Valley, Vicksburg, Miss.

Table E13

Maintenance Dredging on the Ouachita-Black Rivers Waterway*

| Calendar Year | Quantity of Material Dredged, cu yd |
|---|---|
| 1969 | 618,641 |
| 1970 | 935,417 |
| 1971 | 1,706,826 |
| 1972 | 1,369,657 |
| 1973 | 876,345 |
| 1974 | 1,641,079 |
| 1975 | 1,157,564 |
| 1976 | 1,236,583 |
| 1977 | 871,518 |
| 1978 | 1,438,960 |

* File information provided by U. S. Army Engineer District, Vicksburg, Vicksburg, Miss.

Table E14

Selected Bed-Material Sample Collection Stations--Arkansas-White-Red River Basin

| Subbasin | Stream | Station | River Mile | Period of Record Water Years* | Total No. of Days Sampled Through Water Year 1976 | Total No. of Samples Taken Through Water Year 1976 | Re-sponsible Agency** |
|---|---|---|---|---|---|---|---|
| Upper Arkansas River | Arkansas River | Arkansas City, Kans. | 701.4 | 1961-1972 | 79 | 630 | GS |
| | | Near Hutchinson, Kans. | 800.3 | 1961-1969, 1971 | 97 | 767 | GS |
| | | Great Bend, Kans. | 873.2 | 1962-1975 | 59 | 513 | GS |
| | | Kinsley, Kans. | 920.3 | 1961 | 94 | 771 | GS |
| | | Dodge City, Kans. | 970.2 | 1964-1975 | 54 | 435 | GS |
| | Little Arkansas River | Valley Center, Kans. | 17.5 | 1960-1961 | 10 | 80 | GS |
| | Ninnescah River | Near Peck, Kans. | 31.6 | 1962-1969 | 59 | 494 | GS |
| | Ninnescah River (North Fork) | Above Cheney Reservoir, Kans. | 28.2 | 1968-1969 | 29 | 332 | GS |
| | Ninnescah River (South Fork) | Near Murdock, Kans. | 68.0 | 1962-1969 | 82 | 835 | GS |

* Years standing alone indicate the beginning of a period of record of a currently operating station.
** GS - U. S. Geological Survey.

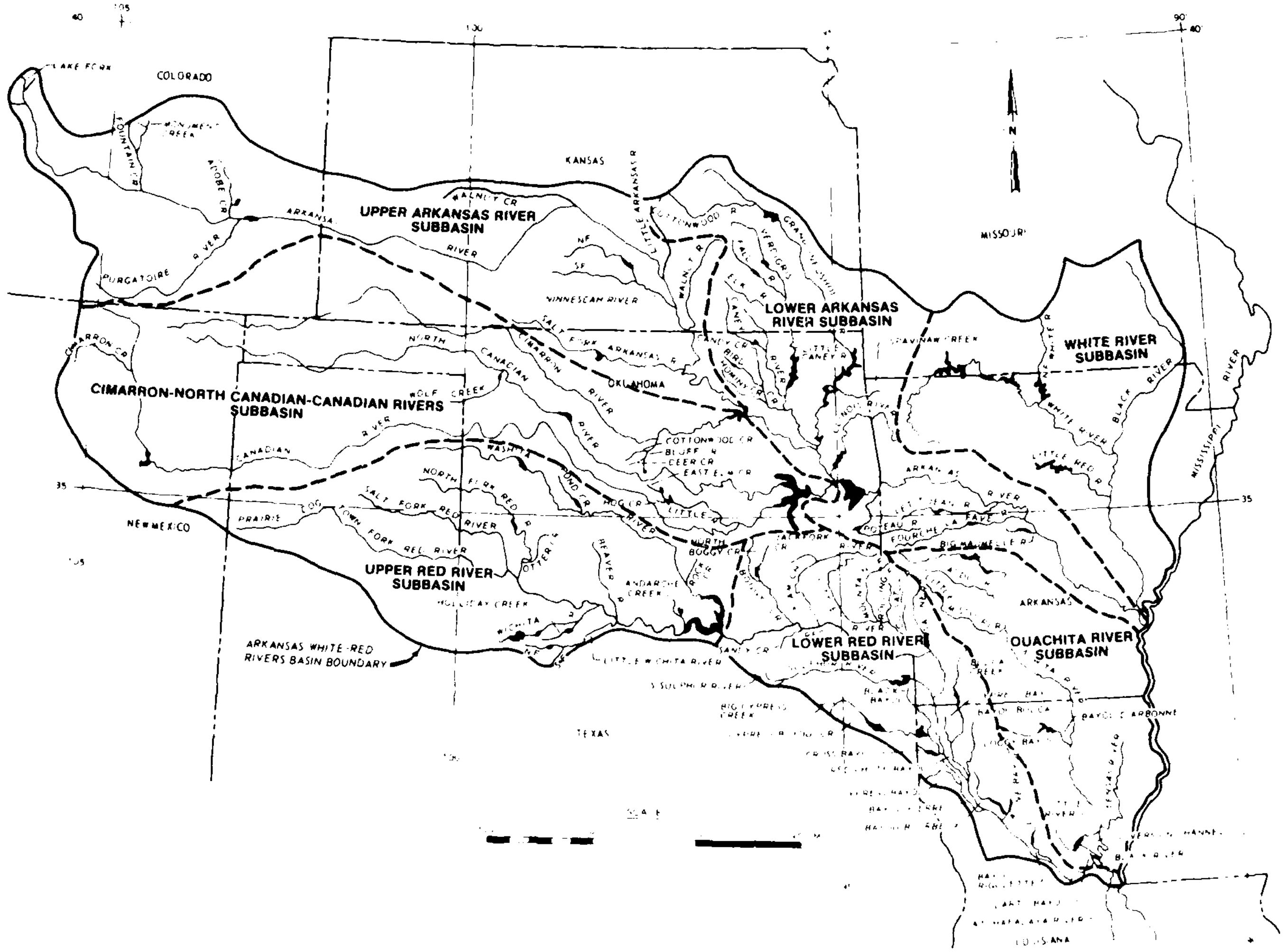


Figure E1. Subbasins of the Arkansas-White-Red Rivers Basin

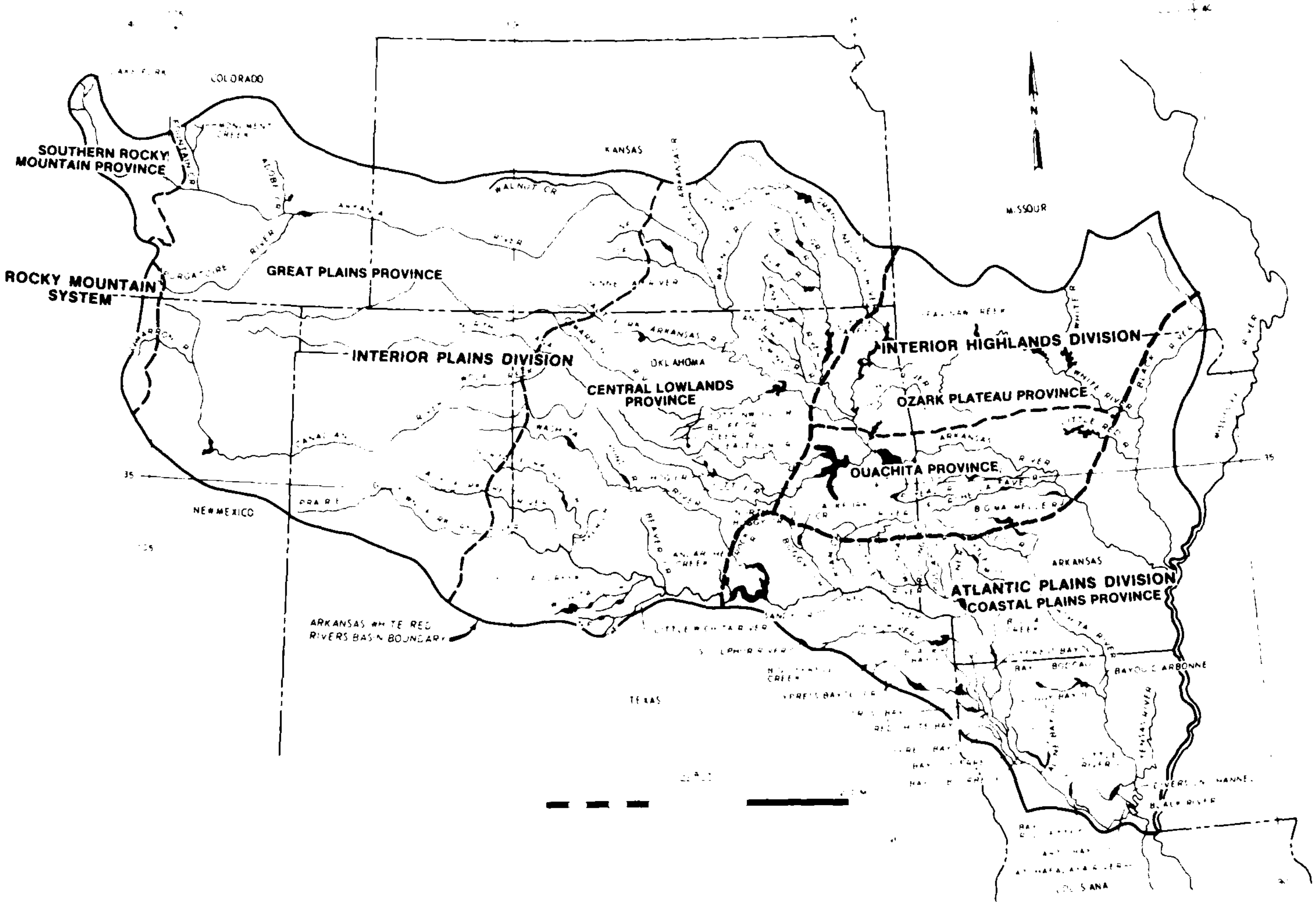


Figure E2. Physiographic map of the Arkansas-White-Red Rivers Basin (Adapted from References 9 and 10)

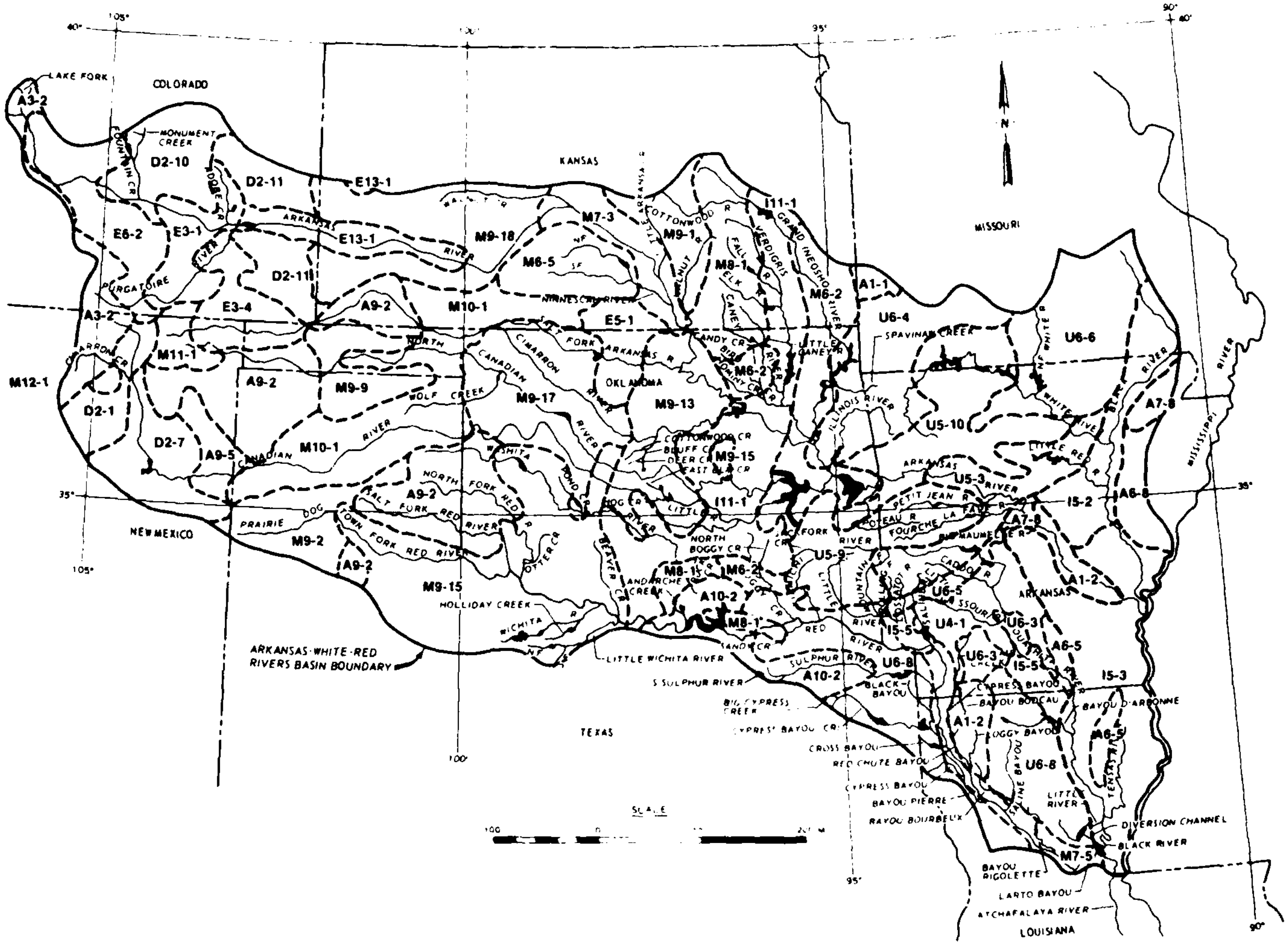


Figure E3. Soils map of the Arkansas-White-Red Rivers Basin (Legend for soil classifications in Table 1 of the main text)

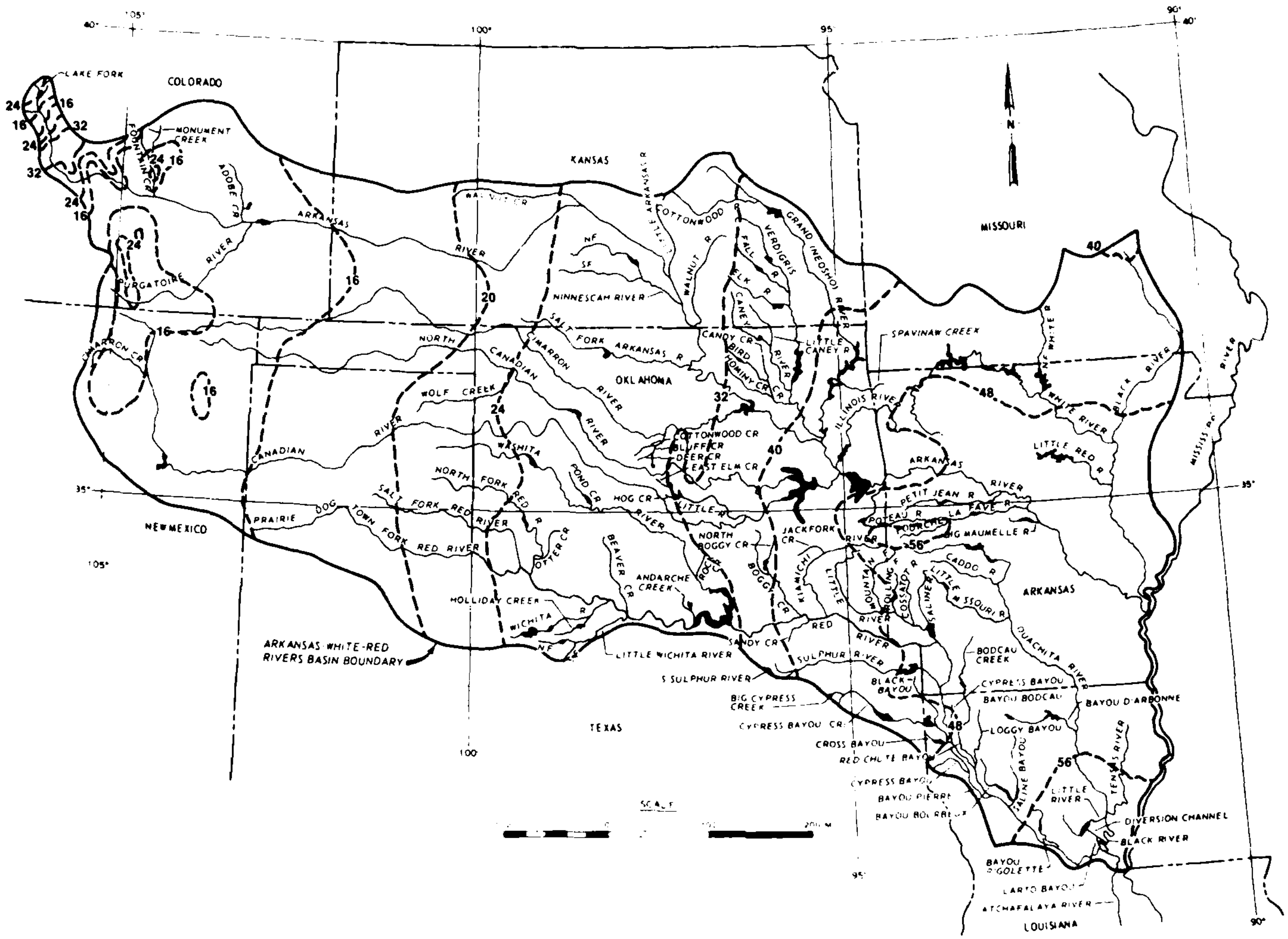


Figure E4. Mean annual total precipitation over the Arkansas-White-Red Rivers Basin (Adapted from Reference 14)

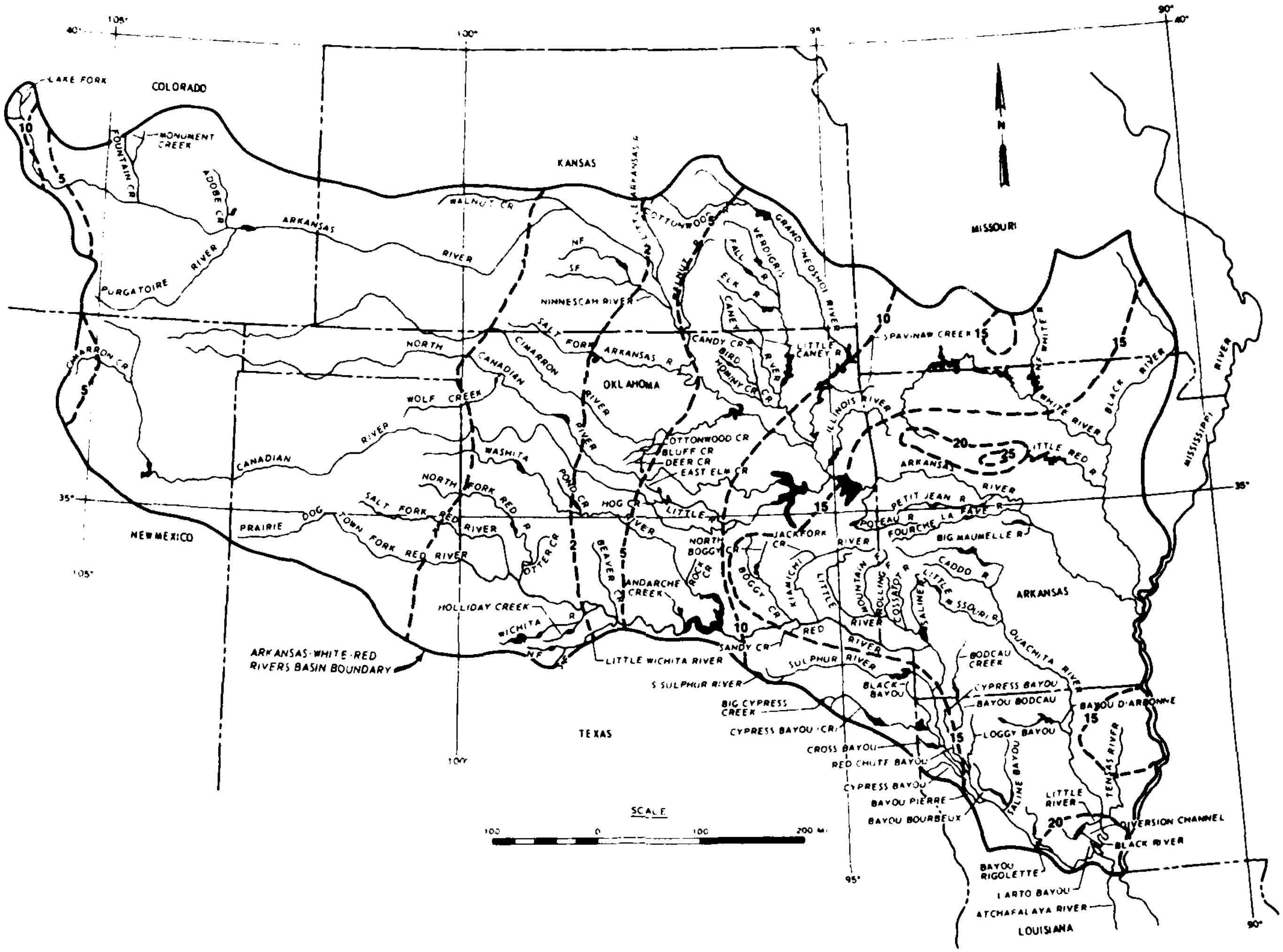


Figure E5. Generalized estimates of mean annual runoff in the Arkansas-White-Red Rivers Basin (Adapted from Reference 14)

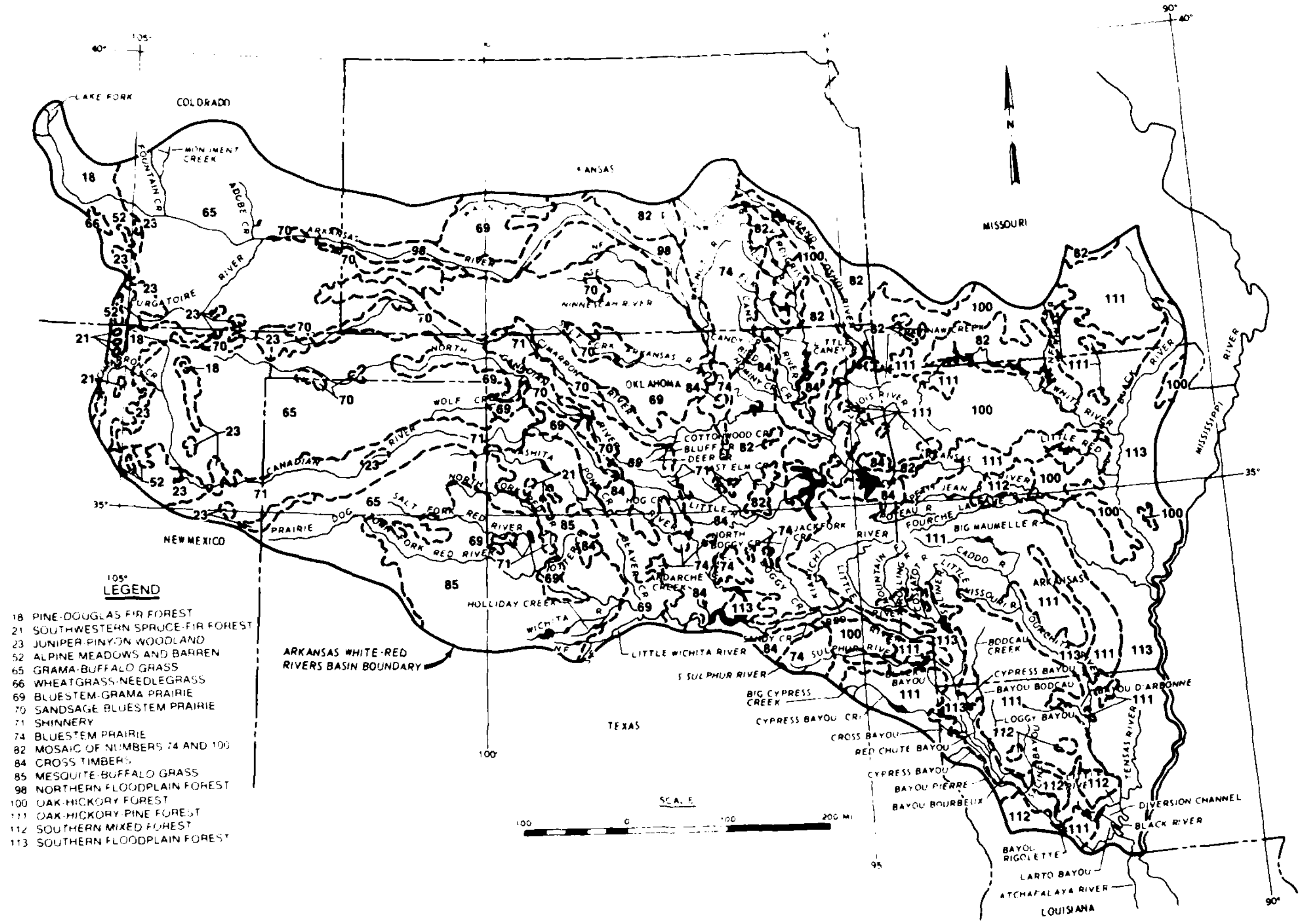


Figure E6. Potential natural vegetation of the Arkansas-White-Red Rivers Basin (Adapted from Reference 15)

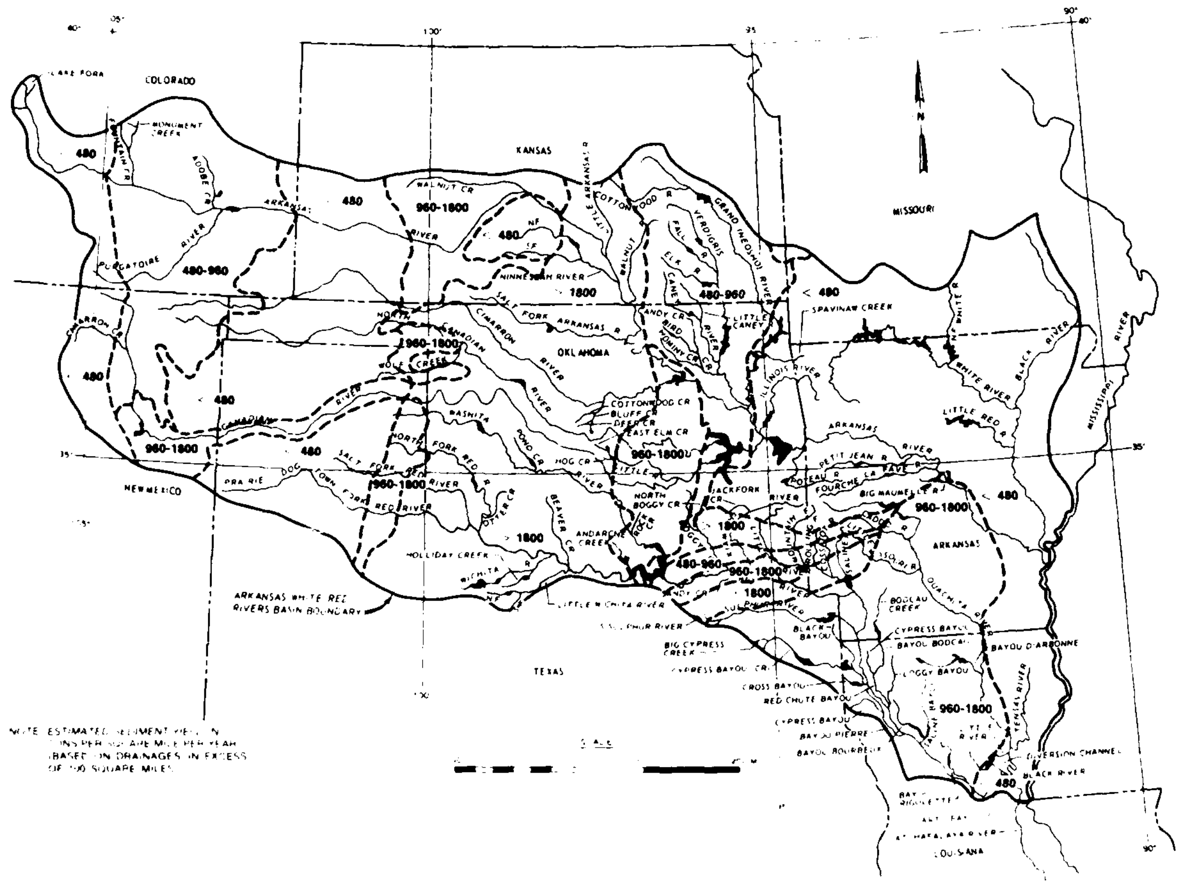


Figure E7. Sediment yield for drainage areas in excess of 100 square miles in the Arkansas-White-Red Rivers Basin. (Adapted from Reference 1)

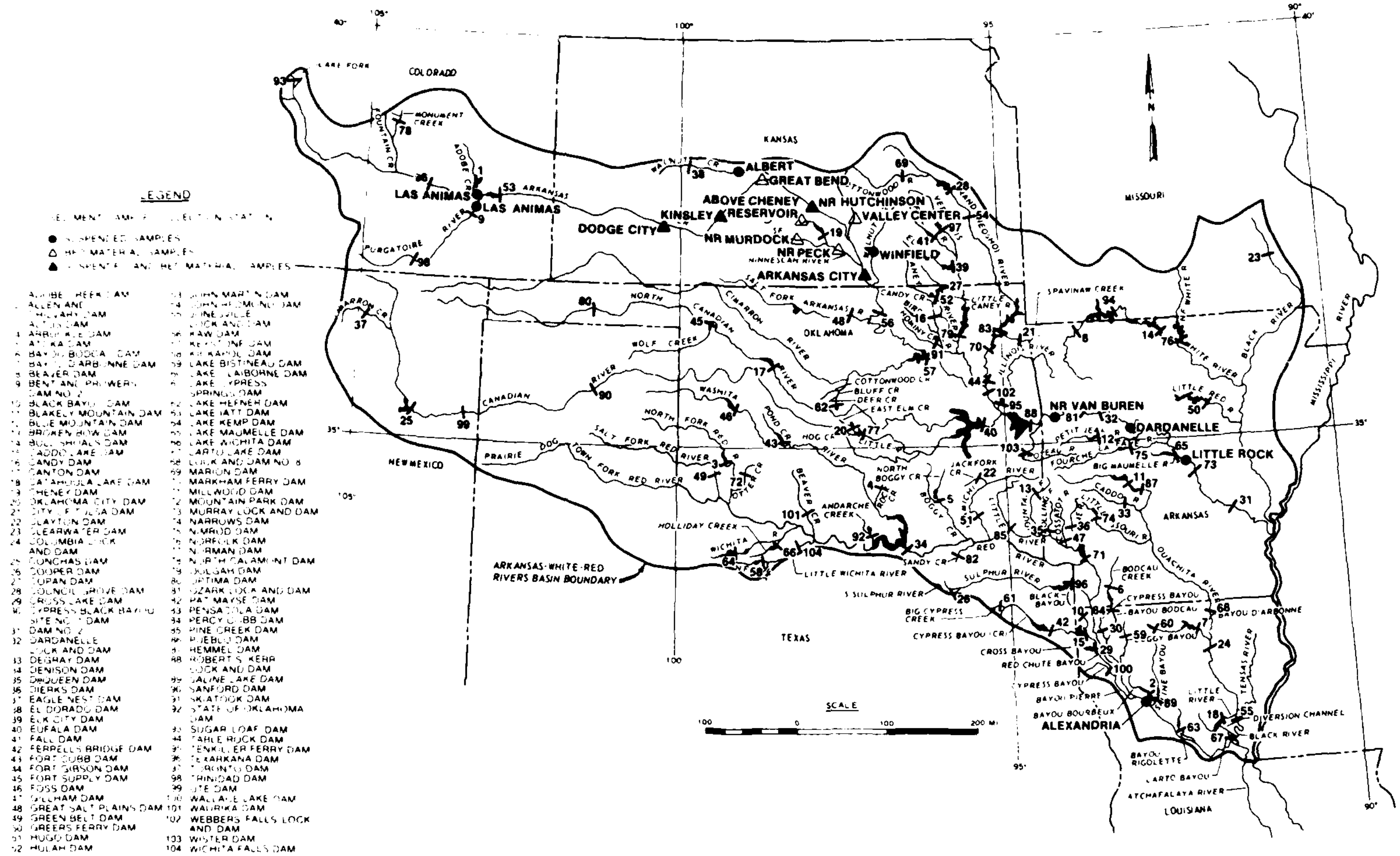


Figure E8. Location of dams and sediment sample collection stations in the Arkansas-White-Red Rivers Basin

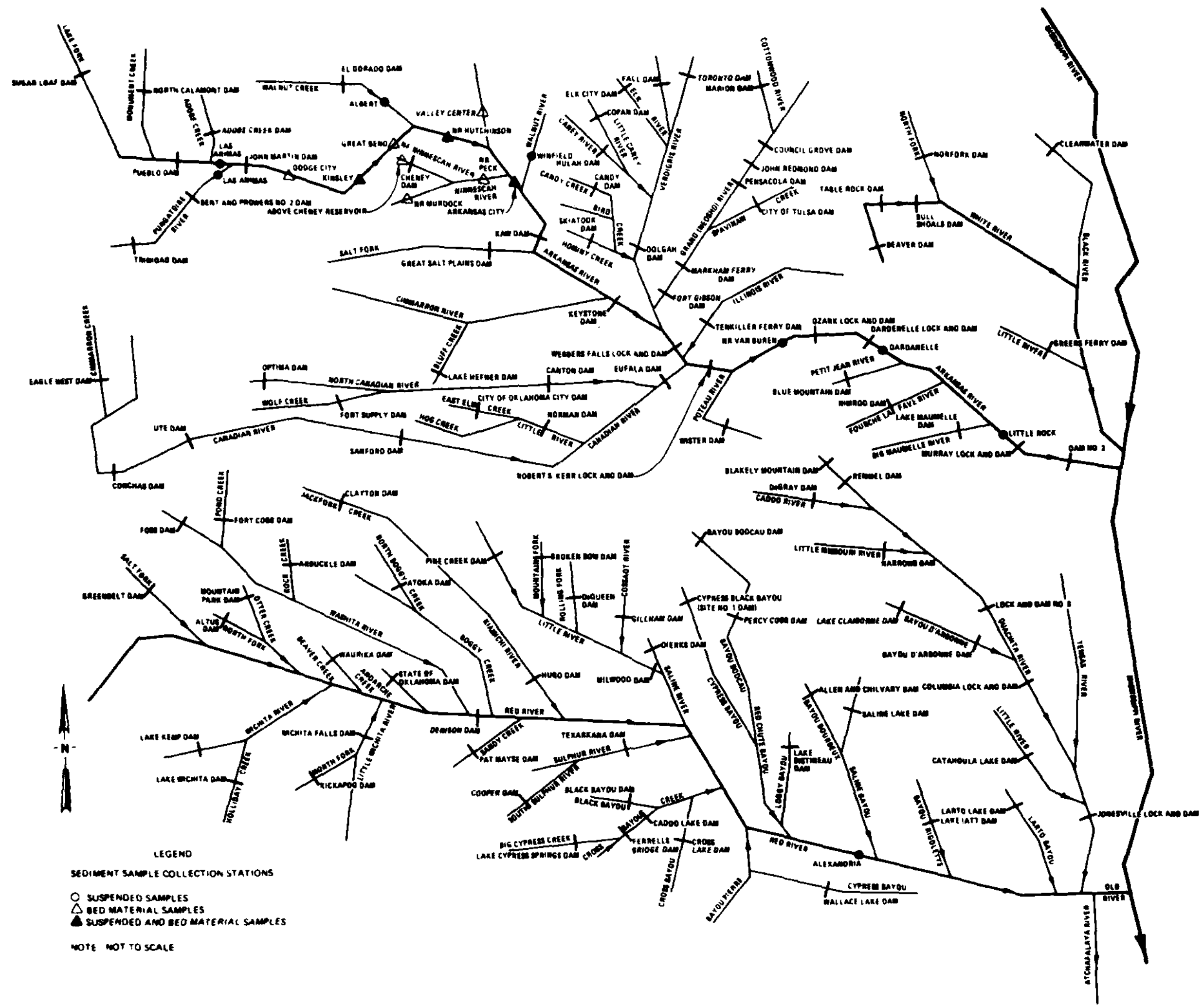


Figure E9. Location of dam and sediment sample collection stations in the Arkansas-White-Red Rivers Basin shown on linear streamflow diagram

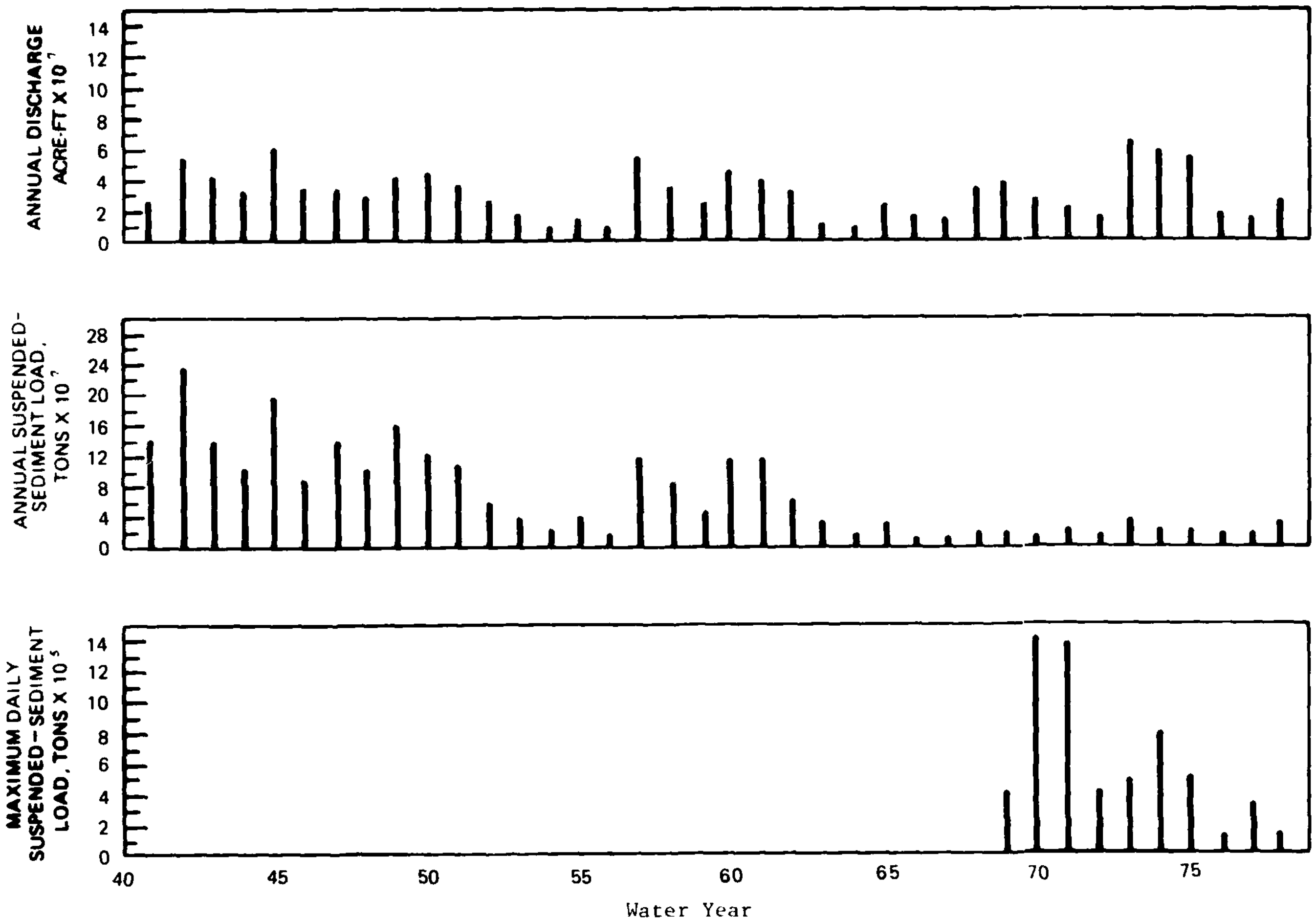


Figure E10. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Arkansas River at Little Rock, Ark. (Note: Figures E10-E18 are presented by subbasin following the listing in Table E9.)

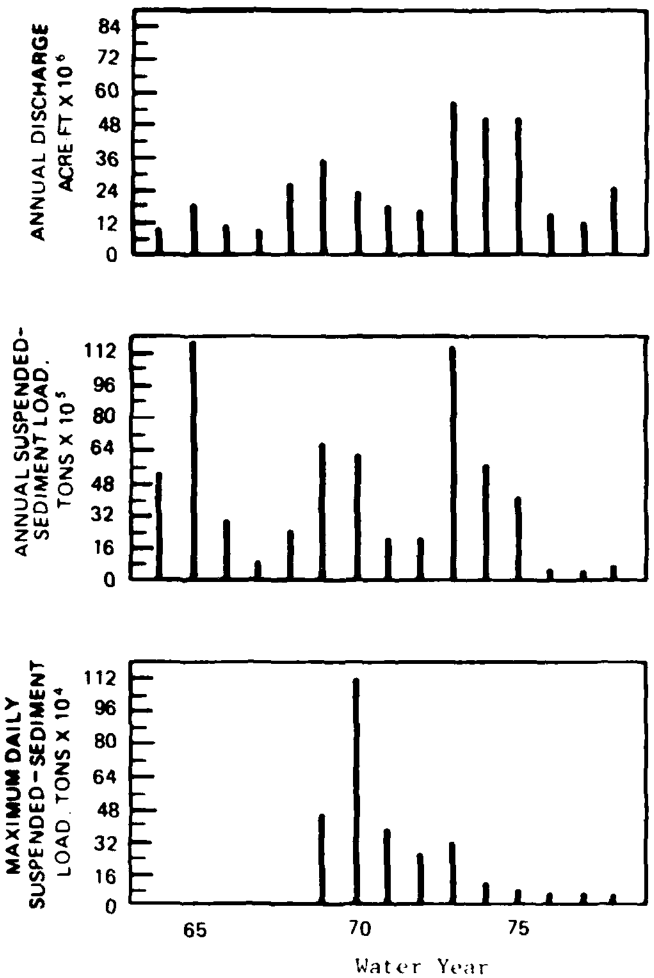


Figure E11. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Arkansas River at Dardanelle, Ark.

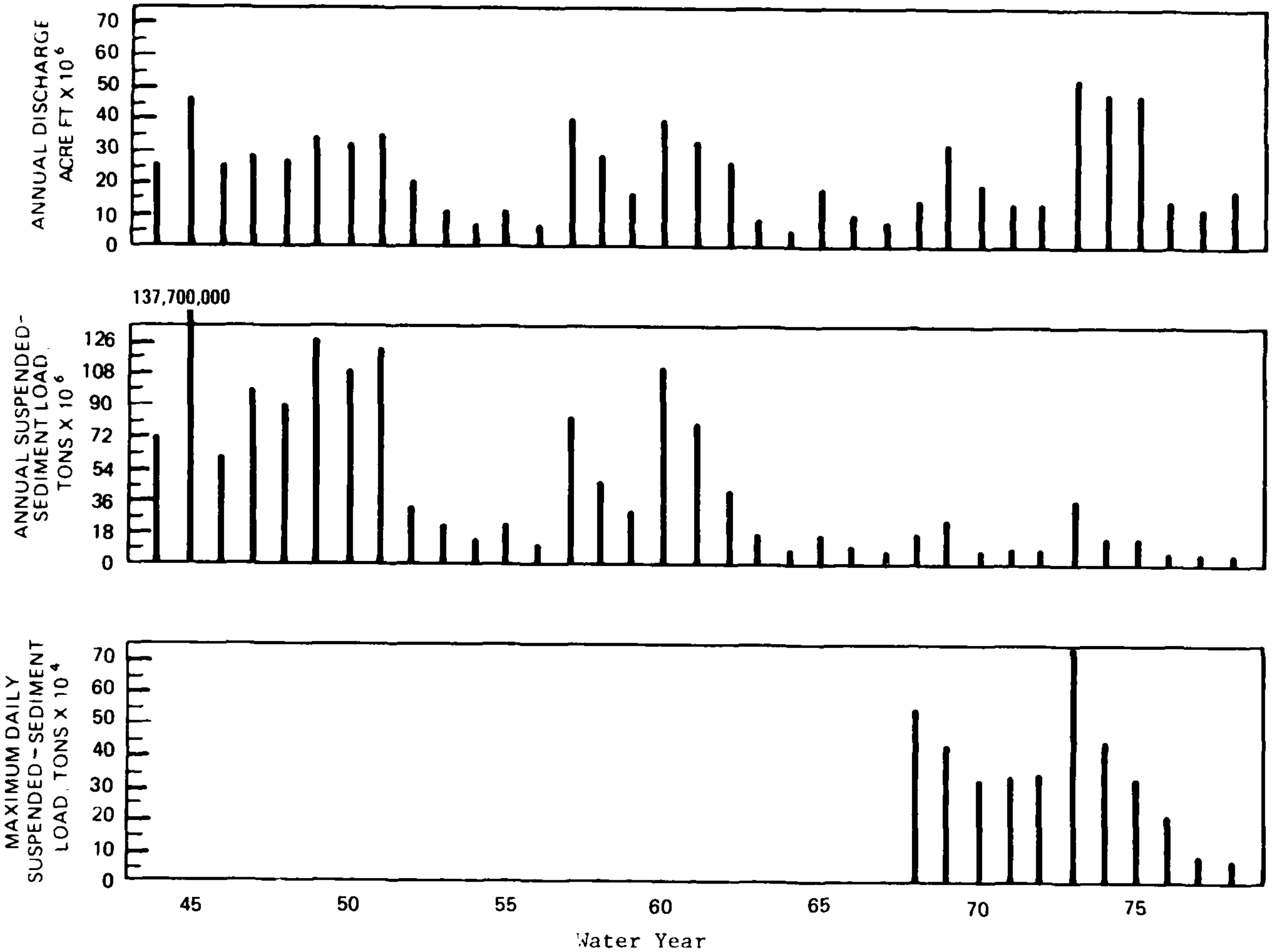


Figure E12. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Arkansas River at Van Buren, Ark.

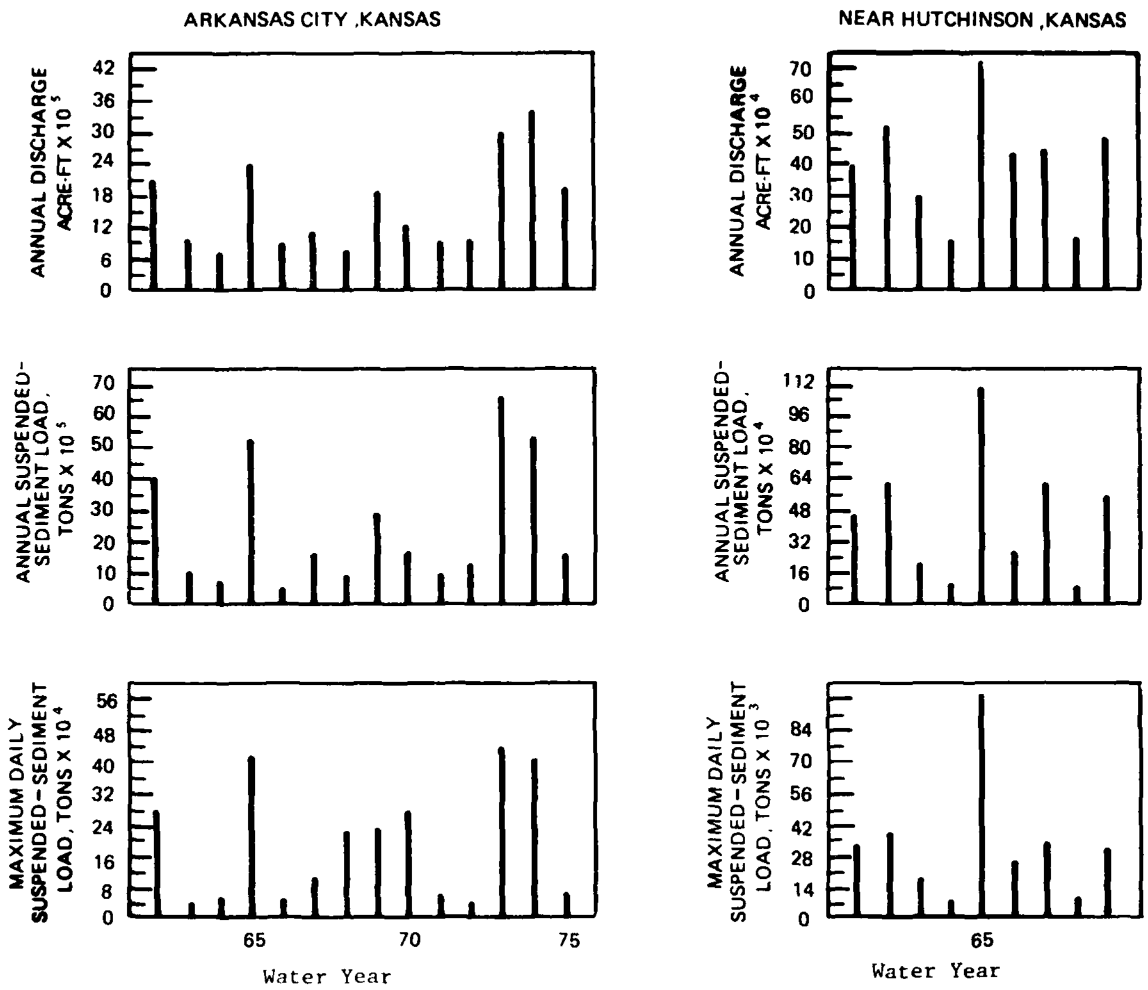


Figure E13. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the stations on Arkansas River at Arkansas City, Kans., and near Hutchinson, Kans.

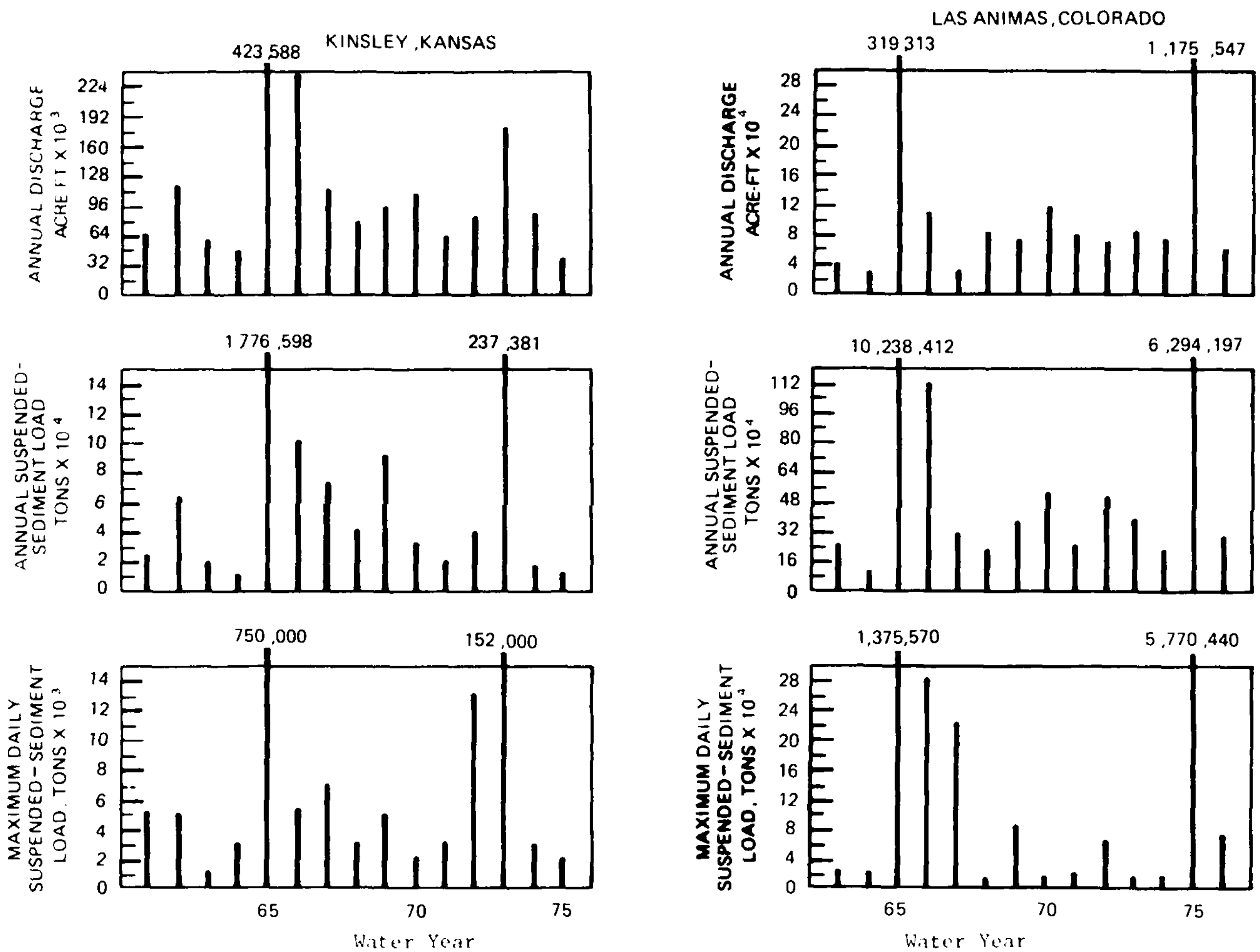


Figure E14. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the stations on Arkansas River at Kinsley, Kans., and Las Animas, Colo.

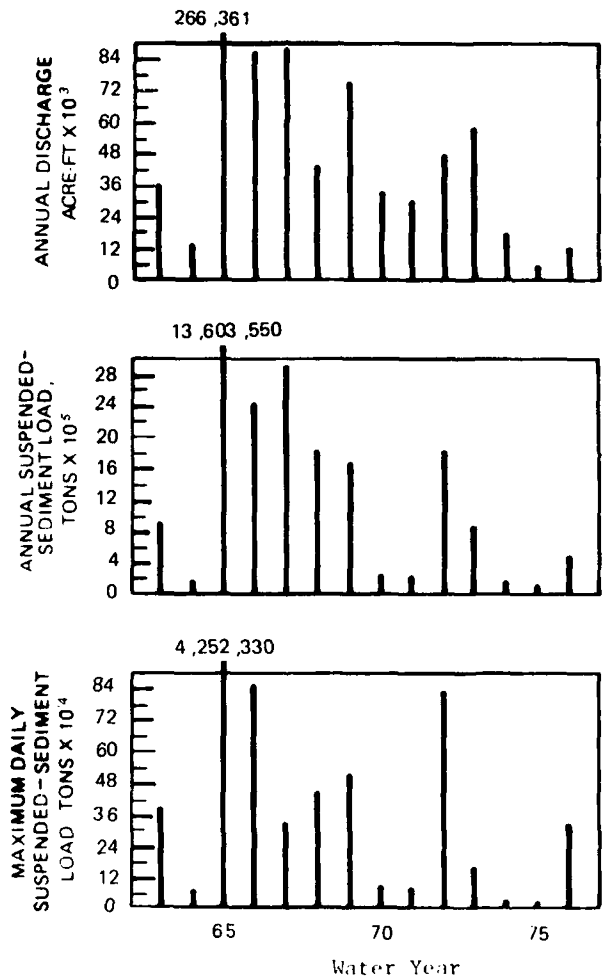


Figure E15. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Purgatoire River at Las Animas, Colo.

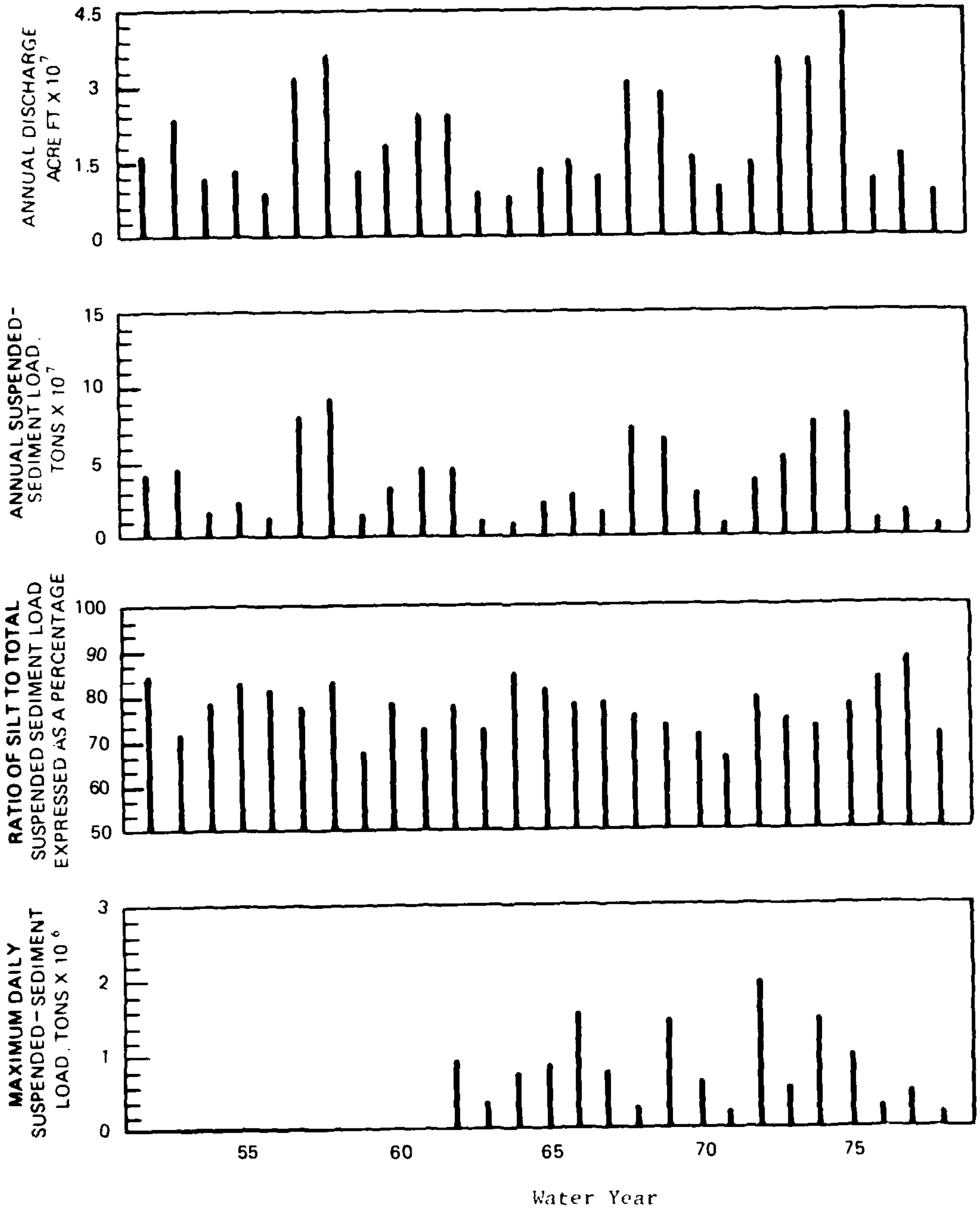


Figure E16. Annual discharge and suspended-sediment load, ratio of silt to total suspended-sediment load, and maximum daily suspended-sediment load for the station on Red River at Alexandria, La.

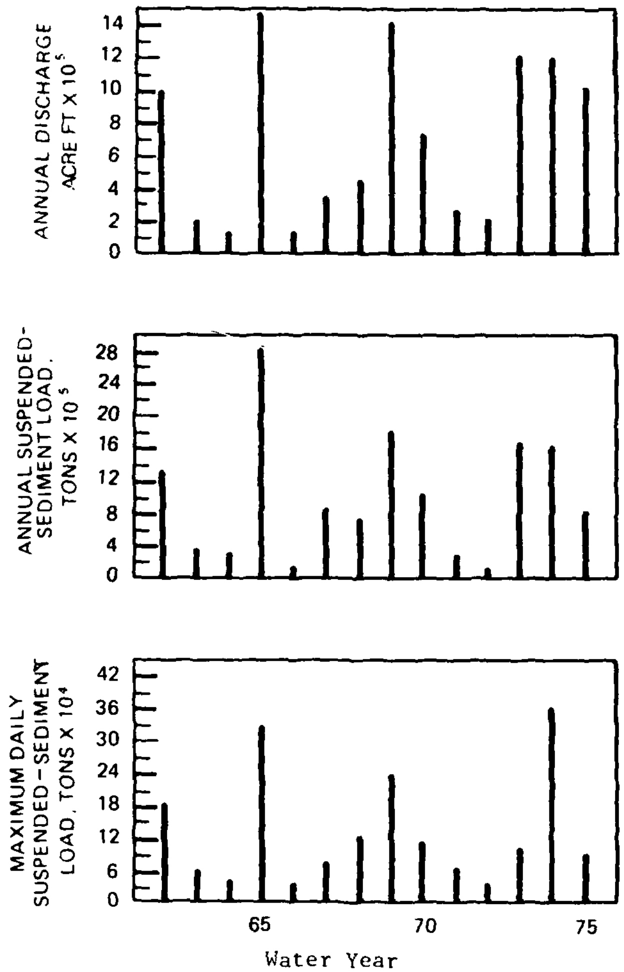


Figure E17. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Walnut River at Winfield, Kans.

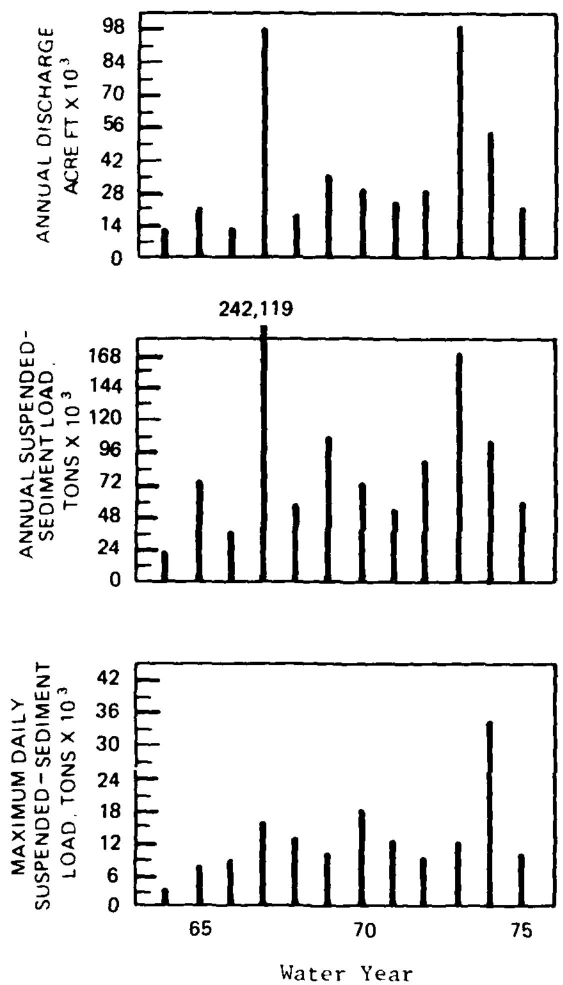


Figure E18. Annual discharge and suspended-sediment load and maximum daily suspended-sediment load for the station on Walnut Creek at Albert, Kans.

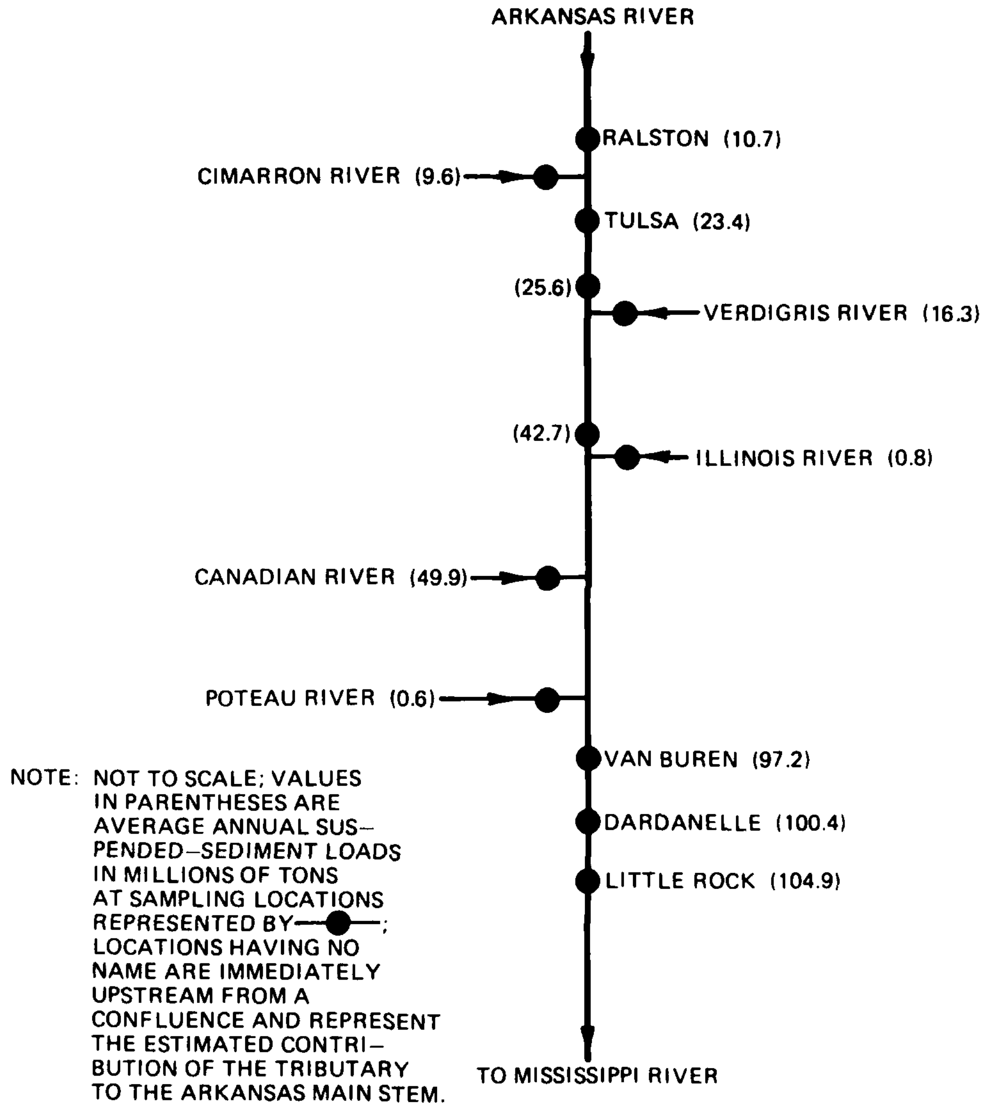


Figure E19. Arkansas River suspended-sediment flow regime prior to construction of major sediment-retention structures (based on 1939-1953 data, Reference 78)

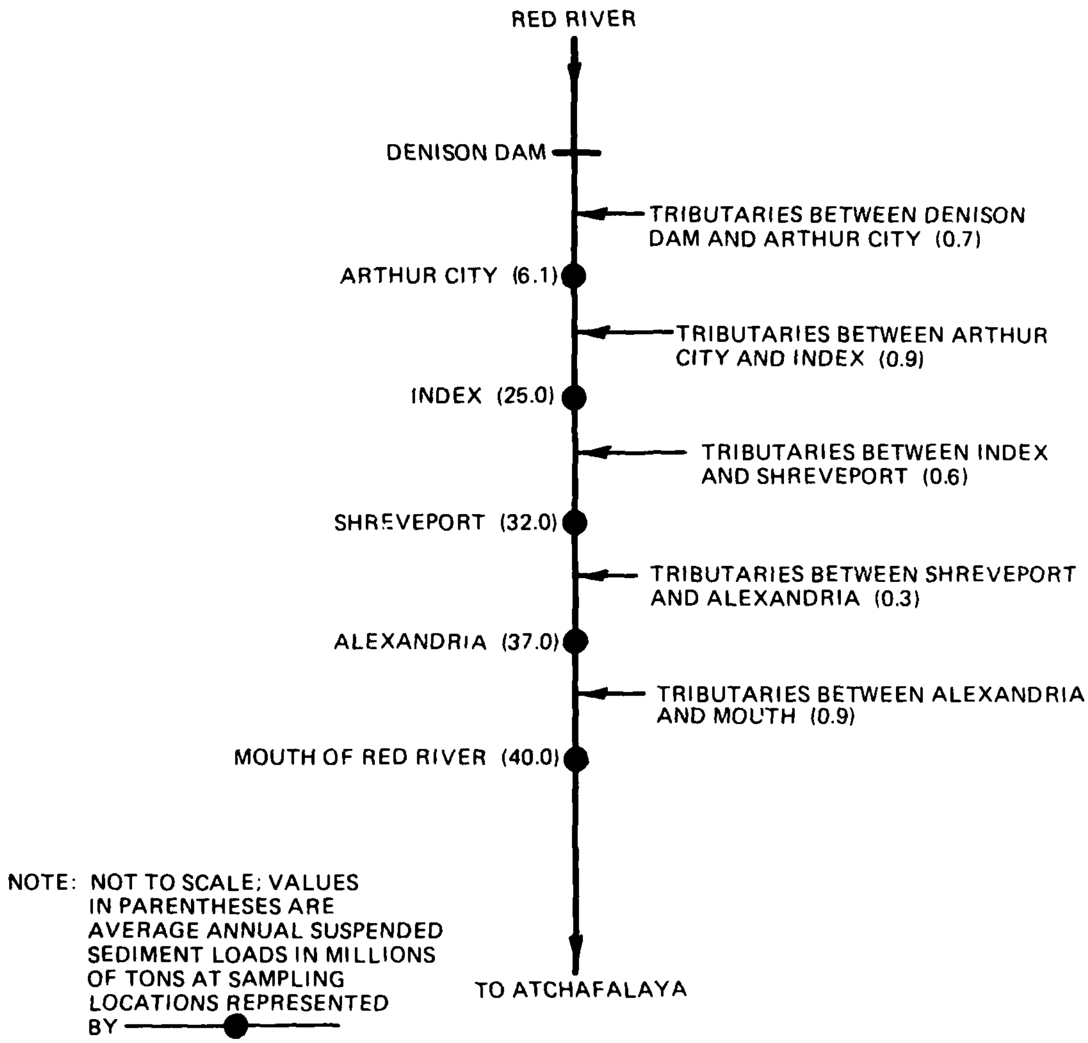


Figure E20. Red River suspended-sediment flow regime with all authorized reservoirs in operation (1968; Reference 4)

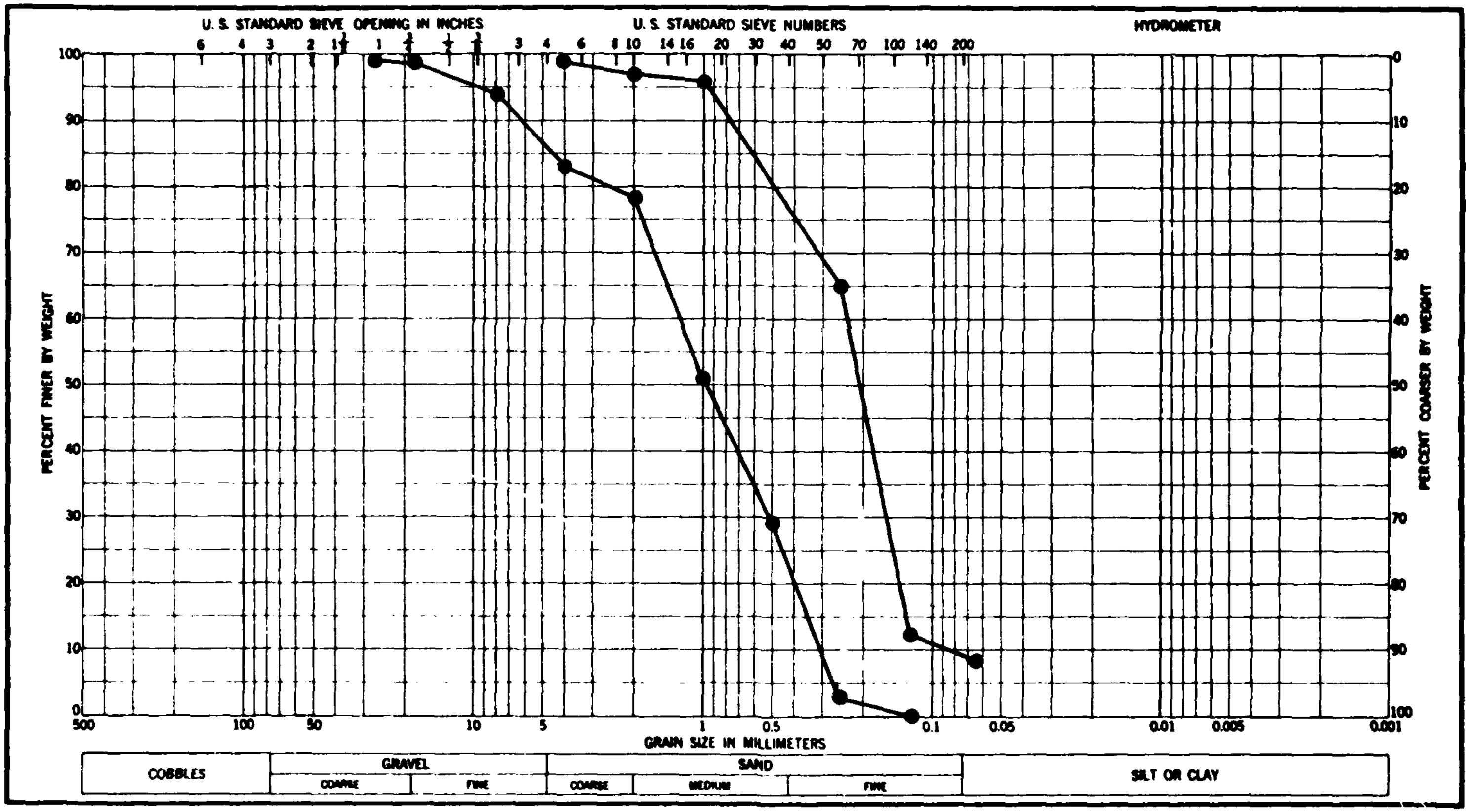


Figure E21. Bed-material gradation envelope for the Arkansas River at Arkansas City, Kans., 1961-1972. (Note: Figures E21-E29 are presented by subbasin following the listing in Table E14.)

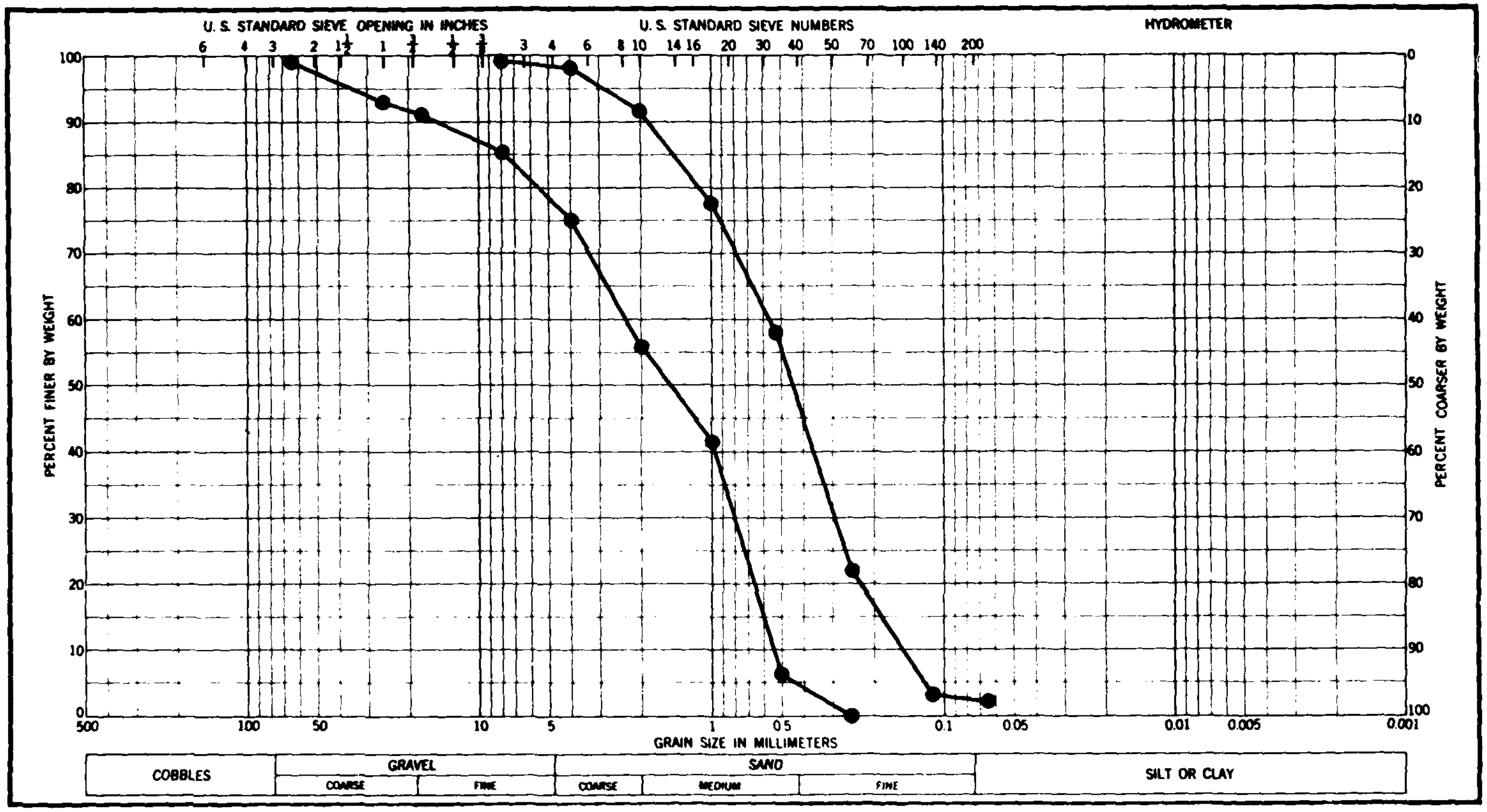


Figure E22. Bed-material gradation envelope for the Arkansas River at Great Bend, Kans., 1962-1975

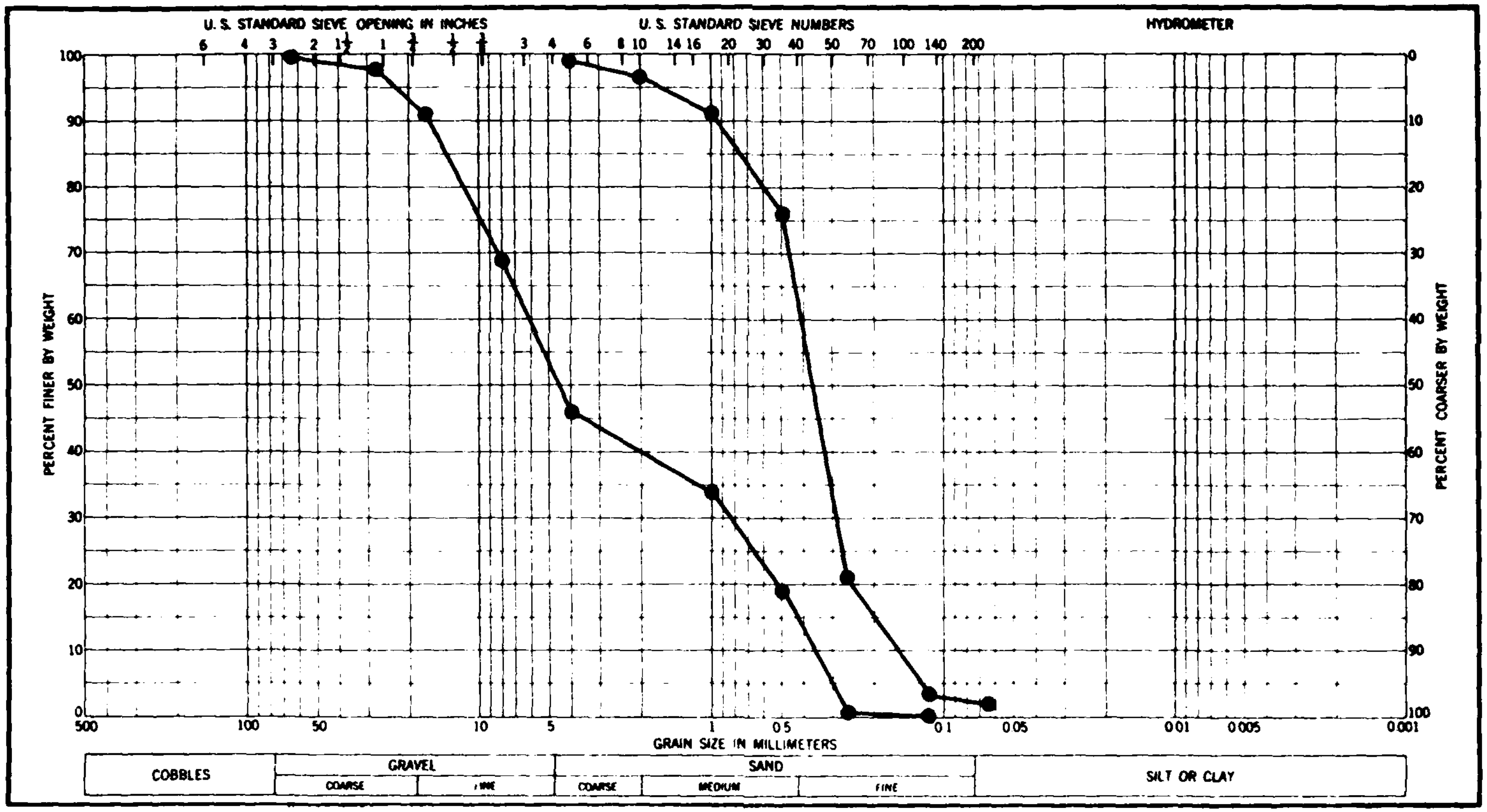


Figure E23. Bed-material gradation envelope for the Arkansas River near Hutchinson, Kans., 1961-1969, 1971-1976

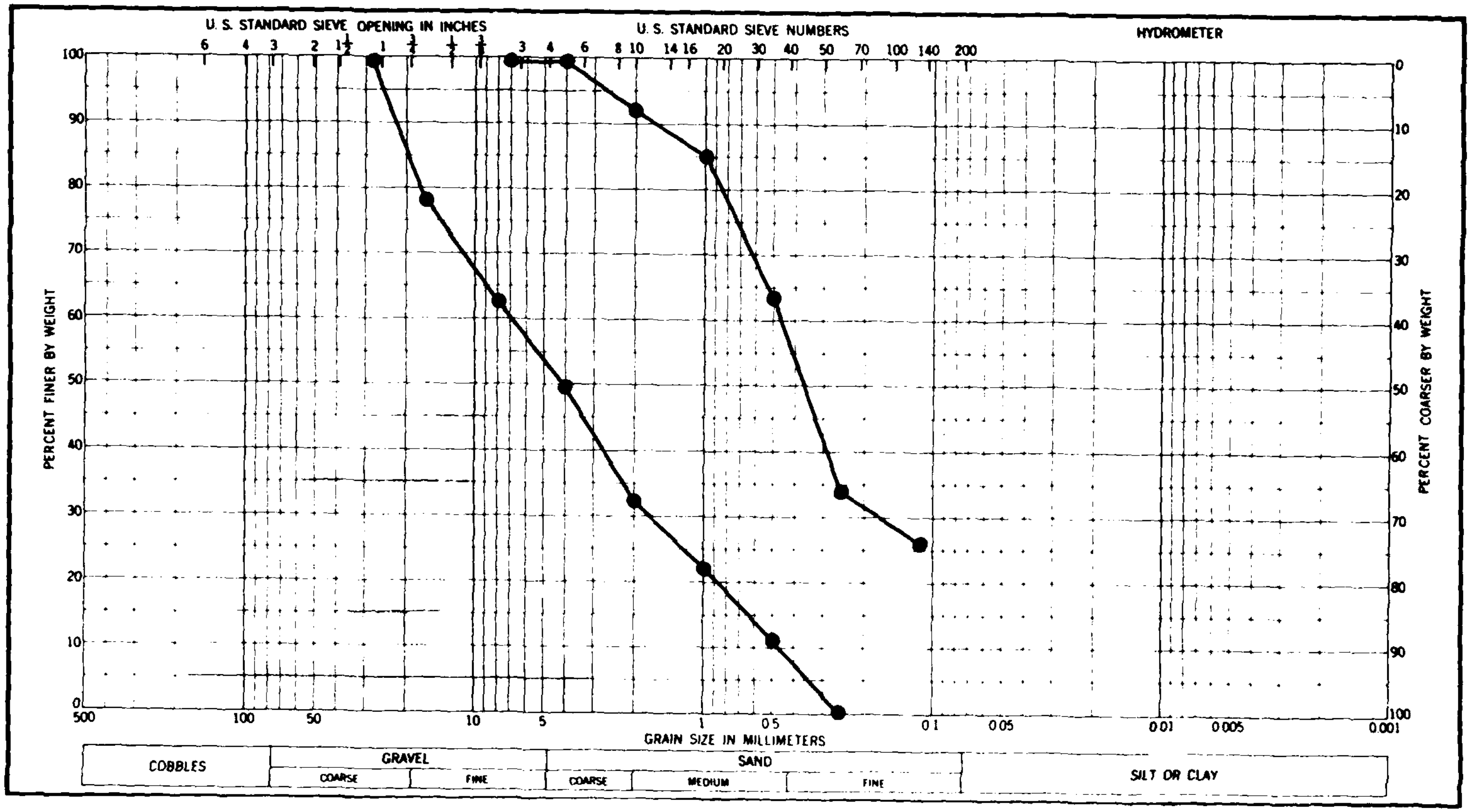


Figure E24. Bed-material gradation envelope for the Arkansas River at Kinsley, Kans., 1961-1976

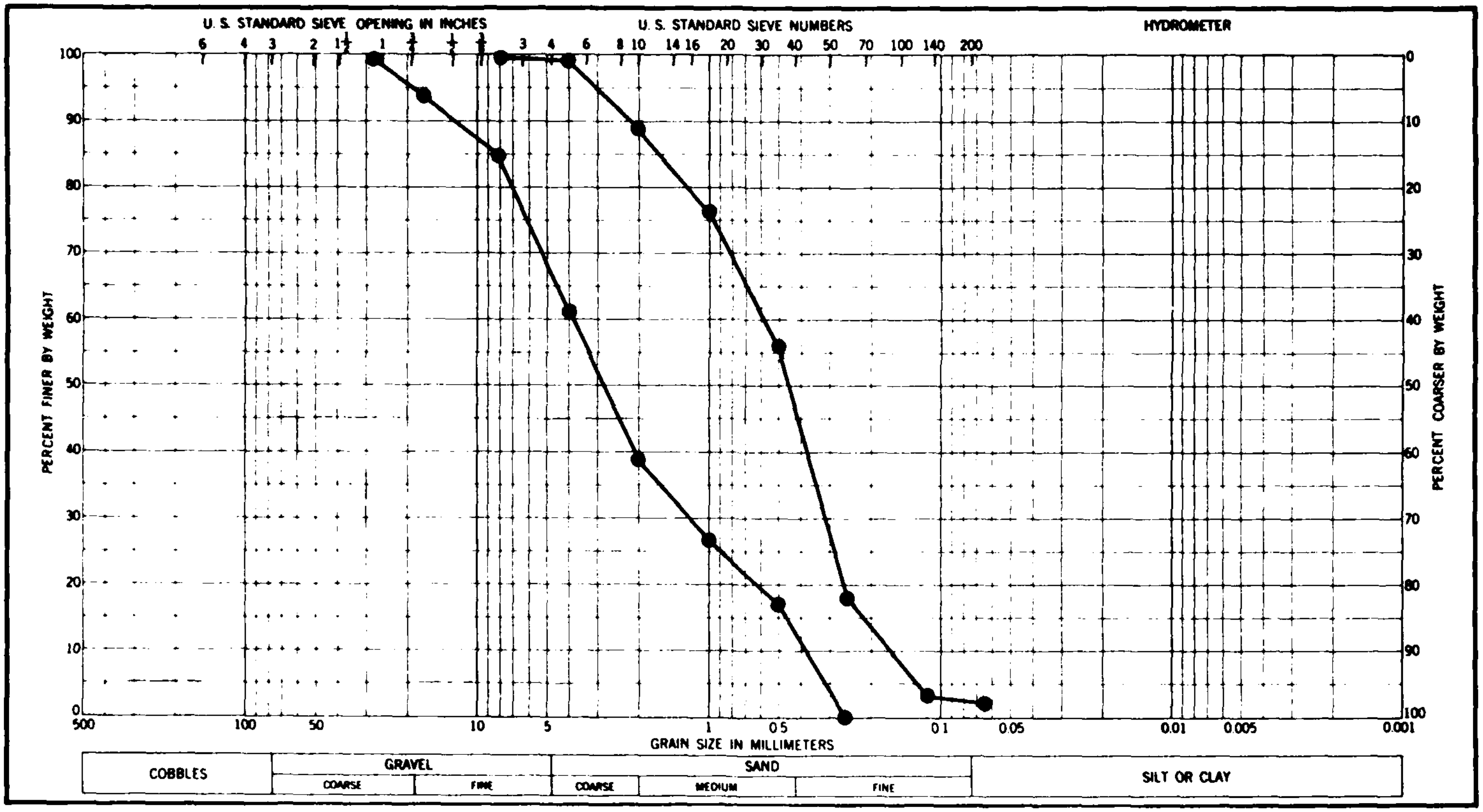


Figure E25. Bed-material gradation envelope for the Arkansas River at Dodge City, Kans., 1964-1975

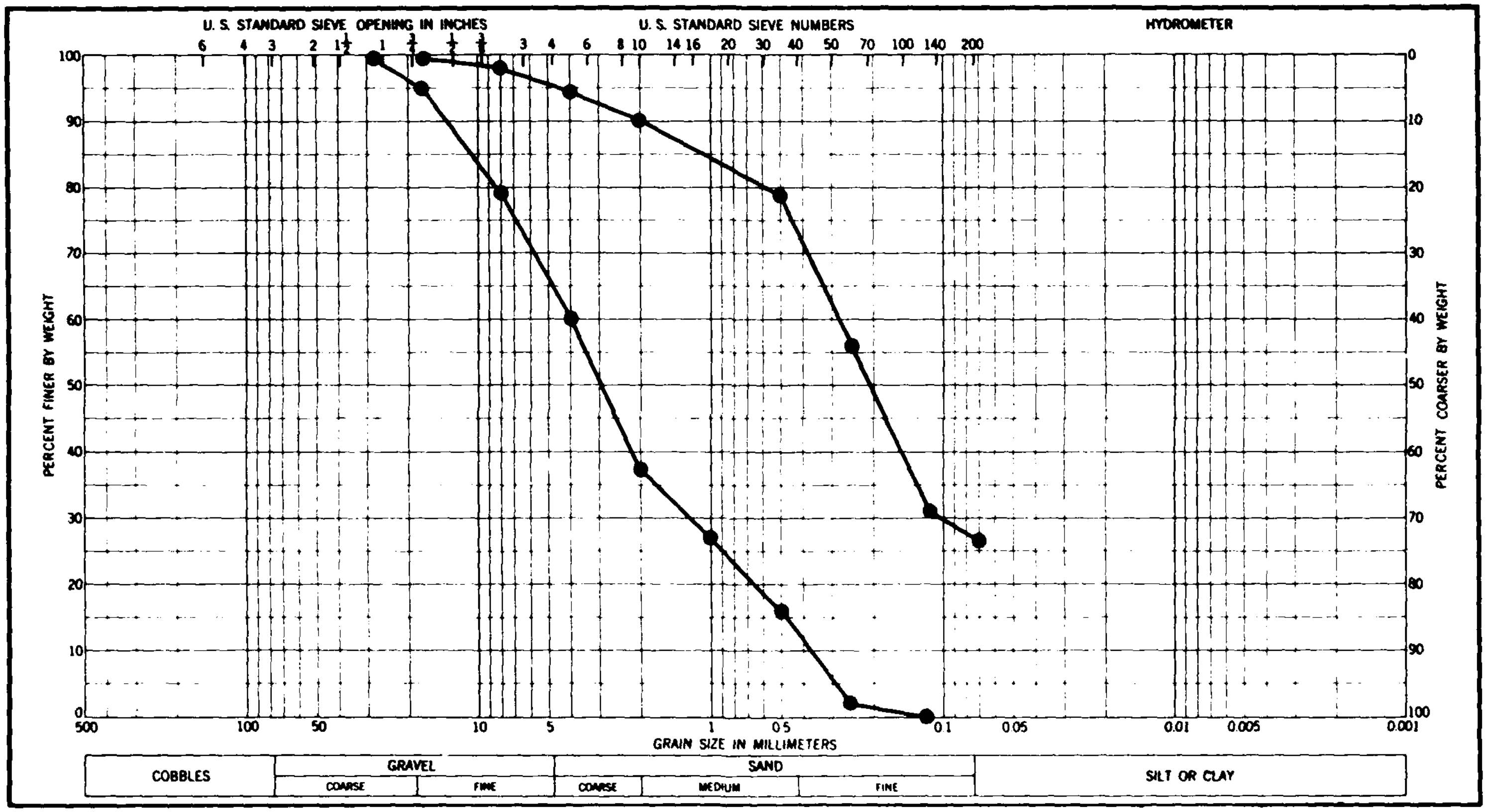


Figure E26. Bed-material gradation envelope for the Little Arkansas River at Valley Center, Kans., 1960-1961

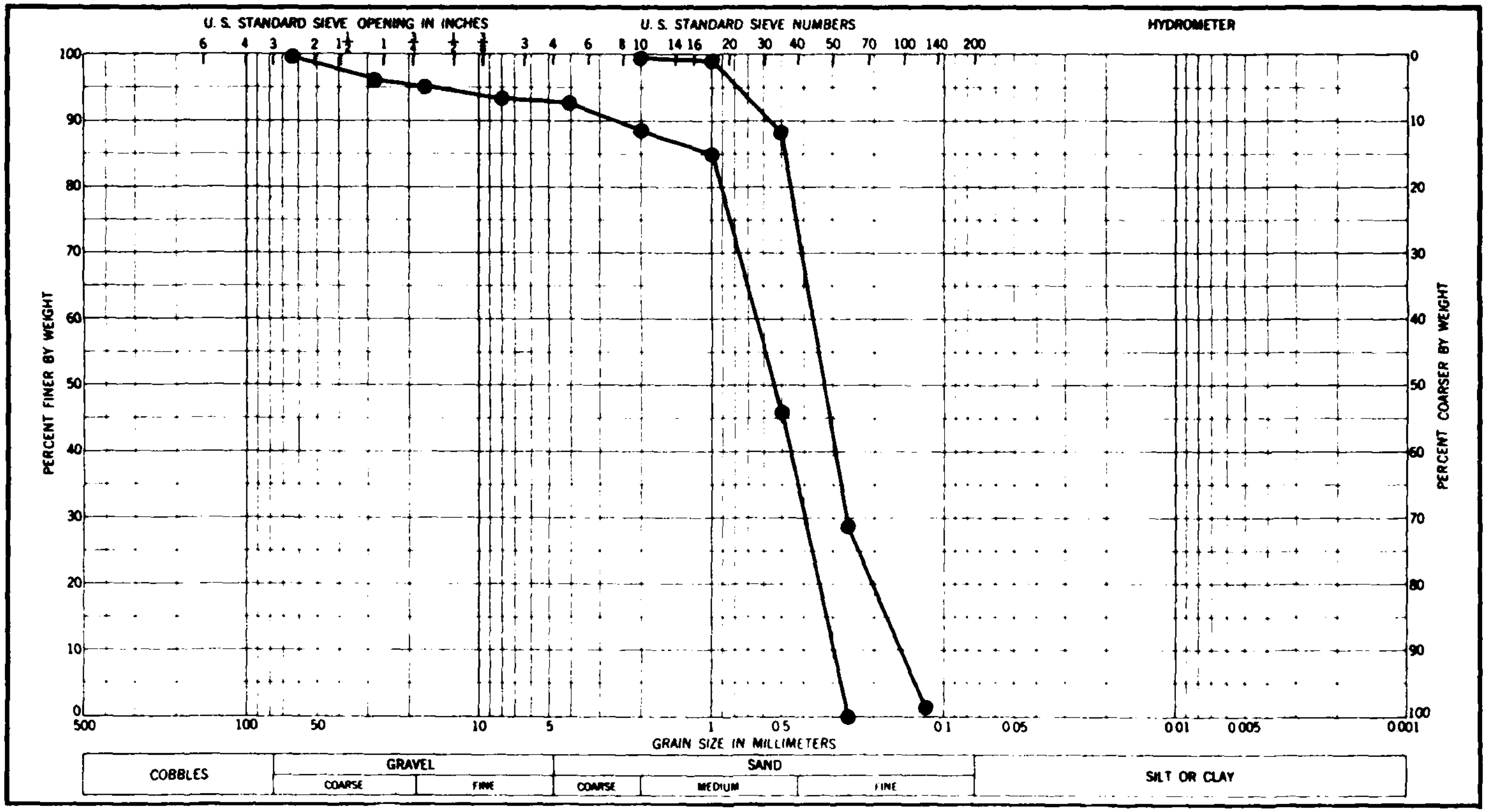


Figure E27. Bed-material gradation envelope for the Ninnescah River near Peck, Kans., 1962-1969

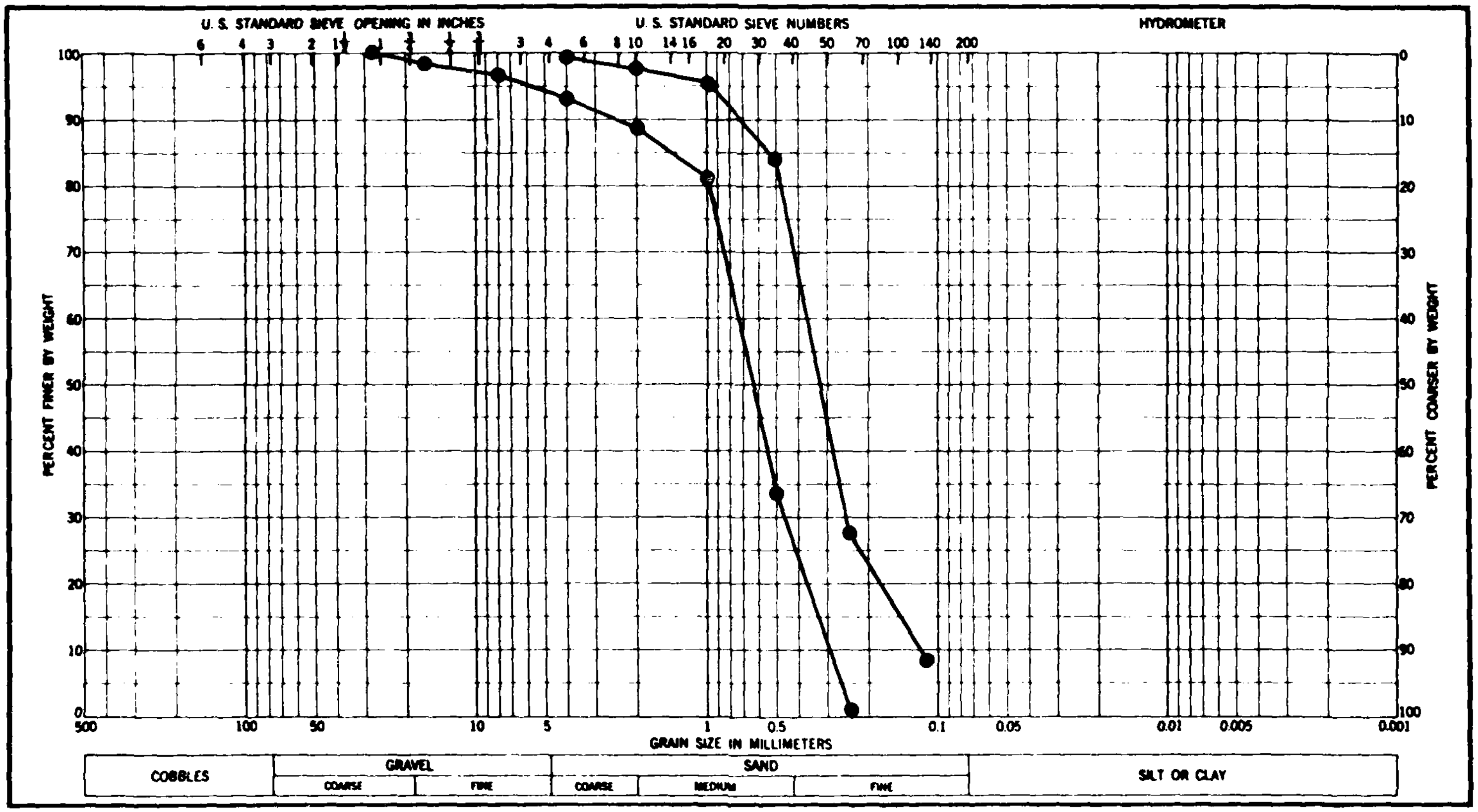


Figure E28. Bed-material gradation envelope for the Ninnescah River (North Fork) above Cheney Reservoir, Kans., 1968-1969

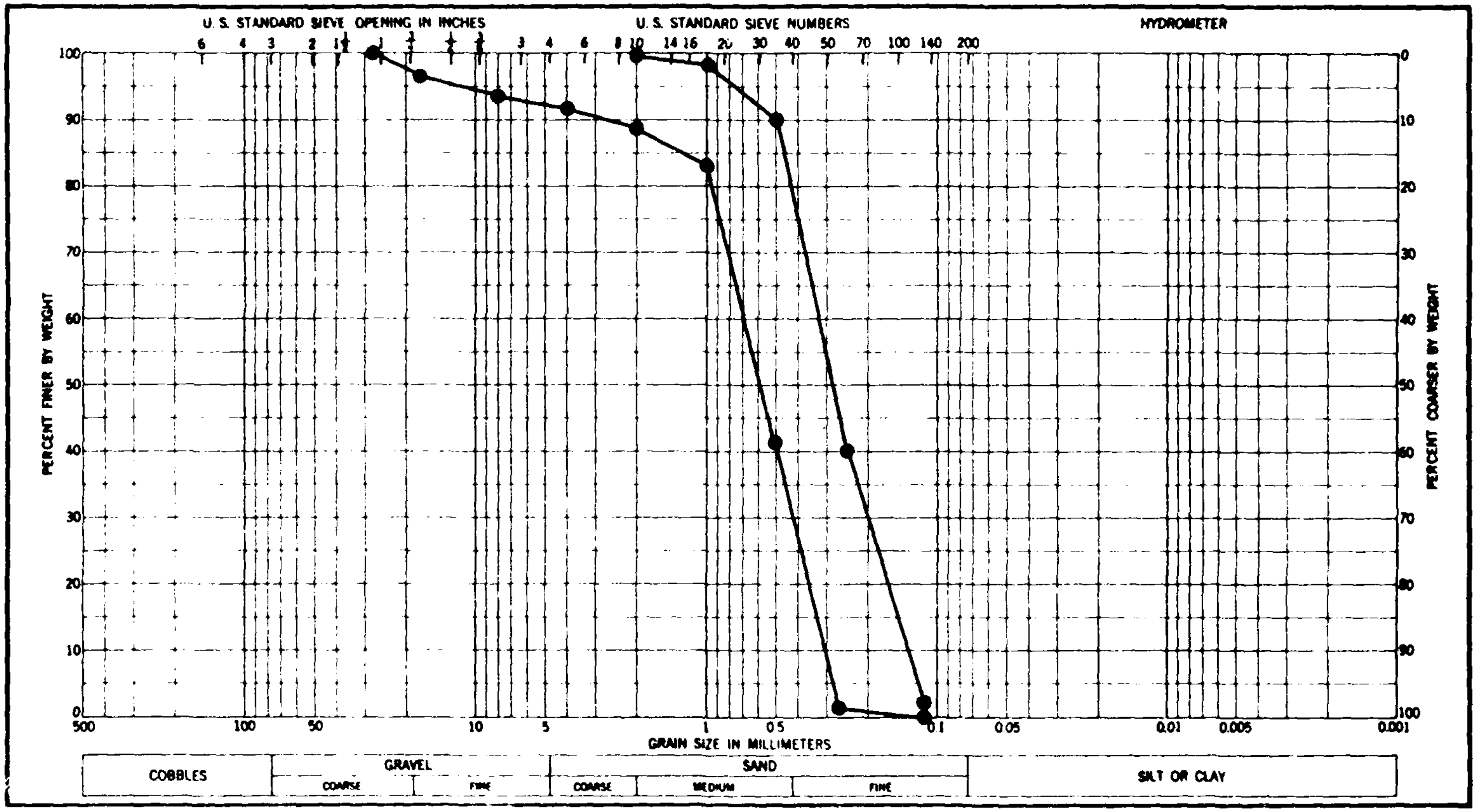


Figure E29. Bed-material gradation envelope for the Ninnescah River (South Fork) near Murdock, Kans., 1962-1969

## APPENDIX F: CHARACTERIZATION OF THE SUSPENDED-SEDIMENT REGIME AND BED-MATERIAL GRADATION OF THE LOWER MISSISSIPPI RIVER BASIN

### PART I: ENVIRONMENTAL CHARACTERIZATION

#### Introduction

1. The Lower Mississippi River Basin includes all drainage from tributaries to the Mississippi main stem downstream from the Upper Mississippi-Ohio Rivers confluence with the exception of the inflow of the Arkansas, White, and Red Rivers.

2. The basin covers portions of six states, extending some 600 miles in a north-south direction and varying in width from less than 50 miles to slightly over 150 miles.[1*] The drainage is composed of six well-defined subbasins: the Atchafalaya River, the Big Black-Homochitto Rivers, Mississippi River main stem, the St. Francis River, the Western Tennessee, and the Yazoo River (Figure F1 and Table F1). A description of these subbasins is provided in the following paragraphs.

3. The Atchafalaya Subbasin is located in south-central Louisiana, running along a north-south axis paralleling the Atchafalaya River main stem. The eastern and western boundaries of the subbasin are the crests of the East and West Atchafalaya Floodway protection levees. The Atchafalaya flows about 140 miles from the junction of the Old and Red Rivers to the Gulf of Mexico near Morgan City, La. This water course is a historic route for the passage of floodwaters from the Mississippi (via Old River) and Red Rivers into the Gulf.** A study conducted in 1953 indicated that under natural conditions the Mississippi River would have changed its course towards the Gulf to a route via the Old and Atchafalaya Rivers sometime between 1965 and 1975.[1] The deterioration of the Mississippi main stem downstream from Old River would have then

* References are listed in the References section at the end of the text of this Appendix.

** Although when the Red was in flood and the Mississippi was not, flow through Old River was often reversed. The reverse flow was last observed in 1942.

been irreversible.[2] If this change had occurred, the cities of Baton Rouge and New Orleans and many smaller communities would have been without sufficient quantities of fresh water to satisfy domestic needs during low-water periods; in addition, the vast industrial complex located from Baton Rouge to near the mouth of the Mississippi would have been without the streamflow needed to maintain river transportation. The effect of the Mississippi's changing its course would have probably been felt as far upstream as Vicksburg on the Mississippi River and Boyce, La., on the Red River, as the result of greater stream velocities and increased meandering. A large number of Federal flood-control and navigation works would have been threatened or lost. The first estimate of these losses, not including the dislocation and disruption of industry and agriculture, was estimated conservatively to be $475,000,000 plus an additional annual maintenance cost of $6,700,000.

4. Public Law 83-780[3] (a modification of the Flood Control Act of 1928), approved September 1954, was enacted by Congress to preserve the present course of the Mississippi and to maintain the balance of flows from the Mississippi into the Atchafalaya. Flow from the Mississippi into the Atchafalaya is now regulated by the Old River Control Structures (which became operational in 1963); the discharge passing these structures travels seven miles through a man-made channel (Old River Outflow Channel), that joins the flow of the Red River at a point some four miles upstream from the Atchafalaya-Red-Lower Old Rivers confluence. Navigation between the Mississippi and the Atchafalaya-Red system is maintained through the Old River Navigation Lock (completed in 1962) and the Lower Old River, which is south of the outflow channel and joins the Atchafalaya and Red Rivers at their confluence. During periods of high water, additional flow can be passed from the Mississippi through the Morganza and the West Atchafalaya Floodways into the Atchafalaya Basin Floodway. The flow from this floodway is then passed to the Gulf of Mexico through the Lower Atchafalaya River and Wax Lake outlets.

5. The Big Black-Homochitto Rivers Subbasin includes all left-bank drainages to the Mississippi main stem from mile 230 to mile 409. The Big Black accounts for 50 percent of the drainage contribution and the

Homochitto 19 percent. Other tributaries to the main stem through this reach are the Buffalo River, St. Catherine's Creek, Coles Creek, and Bayou Pierre, all in Mississippi, and Bayou Sara and Thompson Creek in Louisiana. The Big Black River rises in Webster County, Miss., and flows 270 miles in a southwesterly direction to its confluence with the Mississippi River 27 miles downstream from Vicksburg, Miss.[1] The basin is 155 miles in length and averages 22 miles in width, with a total drainage area of 3,400 square miles. The terrain of the Big Black watershed consists primarily of upland or hill area except for some rolling prairie in Madison County and the alluvial area of the Mississippi River floodplain. The upper reaches of the basin have ridges (with elevations about 600 ft) that are dissected by numerous streams. Elevations in the Big Black main-stem valley range from 350 ft, near Eupora, Miss., to 75 ft near the outlet into the Mississippi River. The Homochitto River has its headwaters near Brookhaven, Miss., and flows in a southwesterly direction approximately 80 miles to join the Mississippi River 22 miles below Natchez, Miss. The total drainage area of the Homochitto River is 1,150 square miles, most of which is hilly timberland. Land surface elevations in the Homochitto River watershed vary from 50 ft along the Mississippi River floodplain to above 500 ft in the upper reaches of the stream.

6. The Mississippi River Main Stem Subbasin consists of that land area adjacent to the main stem downstream from the confluence of the Upper Mississippi and Ohio Rivers including: a. the area between the main-line levees (when there are levees paralleling both banks); b. the area between a bluff and main-line levee (where only one bank is leveed); and c. the area between mainstem bluffs (where no levees are present). This subbasin also encompasses certain areas (not assigned to another subbasin) drained by minor tributary streams that originate in bluff areas (e.g. the area in the vicinity of Vicksburg between the Big Black-Homochitto and Yazoo Subbasins drained by minor left-bank tributaries of the main stem.)[1] About 576 square miles, or 24 percent of the subbasin, is covered with water during normal stages of the Mississippi River. The subbasin is 1,000 miles in length, with the mean width of the

main-stem channel being 0.9 miles. The terrain of this subbasin is very flat with the exception of the loess hills that form the eastern boundary from the vicinity of Cairo, Ill., to below Natchez, Miss. These hills, which are the results of eolian action, are characterized by their almost vertical bluffs. Much of the land is presently used for forest, pasture, and cropland. The main-line levees are often used for grazing beef cattle. The majority of the large cities ir the Lower Mississippi River Basin are located in or adjacent to this subbasin. The economic development of these cities can be attributed in part to the development of the Mississippi River as a major inland waterway. New Orleans has become a major seaport for international trade and has a diversified industry associated with world trade. Baton Rouge is a major shipping and receiving port for crude oil and petroleum products by pipeline, seagoing vessels, and river barges. Memphis, Tenn., is now noted as the largest industrial and transportation center between St. Louis and New Orleans, having excellent water-rail-highway terminal facilities.

7. The St. Francis River Subbasin has an area of 9,250 square miles in Missouri and Arkansas, protected from Mississippi River overflow by 20 miles of levee along the Little River Diversion Canal and 279 miles of Mississippi River main-line levee extending from Commerce, Mo., to the mouth of St. Francis River.[3] The Little River Diversion Canal reroutes flow from 1,200 square miles of hill land in the Little River drainage directly to the Mississippi River at Cape Girardeau, Mo. Small areas of alluvial valley north of New Madrid, Mo., and east of Sikeston Ridge drain to the Mississippi River through floodgates at Big Lake and St. John's Bayou (near New Madrid), and across the Birds Point-New Madrid Floodway through gates in the setback levee at Brewer Lake and the front-line levee at Pea Field Bayou. The major part of the alluvial valley land is directly drained by Little River, which discharges into the St. Francis River. The Little River Watershed area in Missouri has been improved by an extensive system of farm drainage and collection ditches constructed at local expense. The St. Francis River rises in the rugged hill area of southeastern Missouri, and flows southerly 475 miles, passing through the highlands of Crowley's Ridge, to join the Mississippi

near Helena, Ark. (mile 672). Most of the subbasin is a nearly flat alluvial valley, with the main physiographic feature being Crowley's Ridge which extends lengthwise through the subbasin.

8. The Western Tennessee Subbasin includes all left-bank drainages to the Mississippi main stem from near the Tennessee-Mississippi state line to the confluence of the Upper Mississippi and Ohio Rivers excluding drainages originating inside the main-line levee. This subbasin covers over ten thousand square miles including portions of western Kentucky and northeastern Mississippi. The major streams draining this subbasin are the Obion, Forked Deer, Hatchie, Loosahatchie, and Wolf Rivers in Tennessee and Mayfield Creek in Kentucky. The most distinct physiographic feature is the Loess Hills (the result of an epoch of wind aggradation), which parallel the left bank of the Mississippi River.[1] These hills are distinguished by their almost vertical bluffs, rising to about 500 ft at the northern end of the subbasin and declining in elevation toward the south. Crustal movement has played an important role in creating the existing landforms in the northern end of the subbasin. The most conspicuous remnant of earthquakes is Reelfoot Lake, which lies directly over a major fault in the basement rocks of the northwestern corner of Tennessee. The remainder of the subbasin's topography is fairly uniform, ranging from flat along the stream bottoms to rolling hills. Some of the uplands, particularly in that half of the subbasin next to the Mississippi River, are fairly flat and well suited for cultivated crops and pastures. The hills become more rolling towards the eastern boundary of the watershed.

9. The Yazoo River Subbasin, which has a length of 200 miles and a maximum width of 100 miles occupies approximately the northwest quarter of the state of Mississippi. The western boundary of the subbasin is formed by the east-bank levee of the Mississippi River to the vicinity of Vicksburg, Miss., where the boundary becomes the loess bluffs of the Mississippi. The Yazoo River Subbasin can be divided into two distinct areas, the "delta" and hill sections. The "delta" section (western half of the subbasin) lies in the alluvial valley of the Mississippi River and has very flat terrain. The hill section (eastern half of the

subbasin) has a topography that varies from gently rolling to rugged hills. Elevations in the hill section range from 100 ft, to over 600 ft near the northeast corner. The average stream gradient in the hills is 1.5 ft per mile; slopes of the "delta" streams vary from 0.25 to 0.5 ft per mile. The principal streams in the subbasin are the Coldwater River, the Tallahatchie River (with headwaters near Keownville, Miss.), the Yalobusha River, the Big Sunflower River, Steele Bayou, and the Yazoo main stem. Drainage from the Tallahatchie and Yalobusha Rivers unite at Greenwood, Miss., to form the Yazoo, which flows southwesterly through the "delta" 169 miles (with some of the flow being conveyed by the Whittington Auxiliary Channel) to discharge into the Mississippi River at Vicksburg, Miss. (mile 437). The main channel is deeply entrenched throughout its length with bank heights ranging from 30 to 45 ft, respectively, at Greenwood and Satartia, Miss. Channel widths range from 300 to 500 ft. The river is a relatively stable stream with fairly flat slopes and low velocities. Average water surface slopes on the main channel vary from 0.2 to 0.3 ft per mile, with average and maximum velocities being 3 and 5 ft per second, respectively. The Big Sunflower River and Steele Bayou drain the western half of the basin and enter the Yazoo River in its lower section.

## Physiography and Geology

10. The Lower Mississippi River Basin lies predominantly in the Mississippi Alluvial Plain Section of the Coastal Plain Province, a component of the Atlantic Plain Division (Figure F2). A small section of the northern part of the basin lies in the Ozark Plateaus Province of the Interior Highlands Division[1] (Figure F2). The Atlantic Plains Division covers 96 percent of the basin, and the Interior Highlands Division, 4 percent.

11. The Mississippi Alluvial Plain Section is a flat to slightly undulating surface underlain by Pleistocene and Recent alluvial and terrace deposits. The most sharply defined landforms are the coastal plain uplands east and west of the alluvial plain of the Mississippi

main stem. East of the main stem, the uplands area extends from the northern portion of the section into southeastern Louisiana, including a narrow, rugged zone paralleling the main stem called the Bluff Hills, which are characterized by a mantle of wind-blown material (loess). The uplands area west of the main stem are less distinctive and more gently rolling.

12. A small section of the basin lies in the Ozark Plateaus Province of the Interior Highlands Division. This area is a maturely dissected rolling upland developed on gently uplifted rocks ranging in age from Precambrian to Pennsylvanian. The area is characterized by sharply dissected limestone plateaus, with narrow, rolling ridgetops that break sharply to steep side slopes.

13. The Lower Mississippi Basin has been characterized by subsidence accompanied by cyclic transgressions and regressions of the sea since the end of the Paleozoic Era. The subsidence resulted in the formation of the Mississippi Embayment. In Cretaceous times, the embayment was an arm of the sea. The drainage of the central continent, halted by a range of low hills in what would become the state of Missouri, ran north toward the St. Lawrence River. Then came the glacial advance of the Ice Ages. At the edge of the glaciers, about the line depicted by the present Missouri and Ohio Rivers, streams ponded, merged, and sought a new outlet to the south. The falling sea level caused by the formation of the ice sheet had meanwhile emptied the embayment, and across this land, a new river began to incise its course, forming the Lower Mississippi.

## Soils

14. The floodplain and delta of the Lower Mississippi River form the largest continuous area of alluvial soil in the United States (Figure F3; data based on National Cooperative Soil Survey Classification of 1967 compiled by USDA, Soil Conservation Service). During the last glacial age, when the sea level was much lower than at present, the Lower Mississippi River became deeply entrenched between the valley

walls.[3] As the glacial ice melted and the sea level was raised, the valley filled with gravels and coarse sands. The present alluvial plain consists primarily of sand and silt, grading progressively to very fine sand and silt in the lower portion of the basin. Extensive deposits of clay are scattered through the sand and silt deposits. As is typical of rivers flowing in alluvial valleys, the Lower Mississippi has developed a highly sinuous course, creating meander loops and natural cutoffs. The stream has periodically shifted its channel so that parts of the alluvial plain have been worked and reworked by the river on numerous occasions, thus, forming a highly complex depositional structure. Most of the soils are quite fertile and support an extensive agricultural economy.

## Climatology

15. The climate of the Lower Mississippi River Basin is generally described as humid and subtropical, being characterized normally by a mild but definite winter season, with long, hot, humid summers.[1] Precipitation is abundant and well distributed, ranging from somewhat less than 50 in. in the extreme northern portion of the basin to more than 60 in. in the south (Figure F4). The maximum precipitation in the northern area occurs during winter or early spring, and in the southern section, during summer. A significant amount of this precipitation is the result of convective thunderstorms that occur most frequently in June, July, and August. Although droughts do occur, extended periods of severe drought are uncommon, and basin-wide occurrences are very rare.

16. Snow and sleet are minor climatic elements throughout most of the Lower Mississippi Basin. The average annual snowfall ranges from 6 to 12 in. over central Missouri to less than 1 in. from central Louisiana southward. Snow seldom remains on the ground for more than a week in northern sections or for more than a day or two in southern areas. Freezing rain occurs over the region with about the same frequency as snow.

17. The "typical" winter day is difficult to characterize. The

basin is covered for considerable periods with warm, humid maritime tropical air flowing northward from the Gulf of Mexico and the tropical Atlantic. During shorter periods, the region is dominated by very cold, dry continental arctic air. These sharp airmass contrasts make winter a season of strong temperature variability. January daily temperature averages range between 40° and 55°F from the northern part of the basin to the southern. Extreme minimum temperatures vary from -20°F in the north to 10 to 20°F in the south.

18. Summers in the basin are hot. Average daily July temperatures usually ra ge between 78° and 82°F. The extreme maximum temperatures over the region are 100° to 120°F. The relative humidity is generally very high. This combination of heat and humidity produces periods of oppressive sultry weather with little cooling. The usual summer heat in much of the basin resembles that of the tropical wet climates. The growing season is long ranging from 6 to 7 months in the northern part of the basin to from 8 to almost 12 months in the south.

19. Wind directions in the basin vary with the season. By May of most years, persistent southerly winds become dominant and prevail throughout the summer. During late summer and autumn, periods of transitory high pressure over the continent modify the wind flow patterns to easterly or northeasterly. The basin, located just south and east of the most tornado-prone section in the world, has had numerous tornado disasters. Between May and October the area is also subject to hurricanes and tropical storms that can cause considerable damage to the coastal and inland areas.

## Hydrology

20. The Mississippi River drains a basin of 1,232,598 square miles or one eighth of the area of the North American continent. Included in the basin are all or parts of 31 states and 2 Canadian provinces (Alberta and Saskatchewan). Measurements to characterize the flow of this great river system date to the 18th Century when the first gage on the main stem was established at Natchez in 1798 by Governor Winthrop Sargent.

Readings at this gage were continued until 1848.[4]

21. Long-term gaging was initiated on the main stem in 1871 when a station was established at Memphis.[5] Before the year had ended, additional gages had been placed at Natchez, Miss., Vicksburg, Miss., Lake Providence, La., the mouth of the White River, and Helena, Ark. By 1884, twenty-seven stream gages were being used to take daily data on the main stem. Currently, there are several hundred stream-gaging stations distributed over the Lower Mississippi River Basin.

Runoff

22. Annual runoff over the basin is greater than 15 in., with values over 20 in. being found in some areas (Figure F5). This runoff rate is higher than most other major drainages in the Mississippi River Basin. Coupled with the high periodic annual inflow from the Upper Mississippi, Ohio, and Arkansas Rivers, the Lower Mississippi Basin, in its natural state, was highly susceptible to flooding. The construction of a massive levee network along the Mississippi main stem and some of its tributaries has mitigated the flood threat.

Groundwater

23. Aquifers containing fresh groundwater underlie the entire basin except for parts of coastal and central Louisiana.[1] In some areas, fresh water extends to depths of more than 3,000 ft, while in other areas to less than 100 ft. Two or more major aquifers underlie most localities in the basin, offering a choice for meeting requirements of quantity and quality. The average aquifer volume storage is estimated to be about 75,000 acre-ft per square mile, a quantity sufficient to cover the basin to a depth of about 120 ft.

24. Groundwater withdrawals in the basin during 1970 averaged 8,290 cfs. About 45 percent of these withdrawals were used for the irrigation of crops in the St. Francis River Subbasin. Irrigation was the leading use of groundwater withdrawals over the entire basin, averaging 5,390 cfs during 1970. Industrial and municipal withdrawals totaled 1,280 and 625 cfs, respectively. Because good quality groundwater is generally available when needed, wells provide most of the public and industrial water supply in the Lower Mississippi River Basin.

In a few localities, the demands for groundwater have exceeded or are approaching the economically practicable limit of available supply; in most areas, however, the water supply potential is more than adequate to meet present requirements. The dependable yield from aquifers in the basin is conservatively estimated to be in excess of 8,000 million gpd.

25. In the northern part of the basin, the natural movement of groundwater in the Cretaceous and Tertiary aquifers was toward the axis of the Mississippi Embayment. Water moved from upland recharge areas to areas of natural discharge in the Mississippi Alluvial Plain. In Louisiana and southwestern Mississippi, the regional groundwater movement was southward toward the Gulf of Mexico with hydraulic gradients being low, probably less than 2 ft per mile. The regional movement of water in the Mississippi River Valley Alluvial Aquifer was and is southward except in the vicinity of large streams. The hydraulic gradient is probably 1 ft per mile or less, or about the same as the slope of the surface of the alluvial plain. The historic direction of movement in some aquifers has now been altered considerably, even reversed, in the few areas where large quantities of groundwater are being withdrawn.

Flooding

26. Historically, floods have been a serious problem in the basin. The first recorded flooding along the Mississippi River was described by Garciliaso de la Vega in his history of DeSoto's expedition.[4] The Spaniards witnessed this flood from the vicinity of an Indian town probably located on the left bank of the river a short distance downstream from the mouth of the Arkansas River. The historian recorded this 80-day flood as being severe, beginning about 10 Mar 1543 and cresting about forty days later.

27. The current level of economic and social development would not have been possible without the flood-control and drainage programs that have been an integral part of cultural activities in the basin since the earliest days of settlement.[1] In the beginning, these programs were rudimentary efforts by individual riparian holders to protect their own lands from the annual rises of the Mississippi and its tributaries. In time, this responsibility was shared by not only individual landowners,

but also by county and parish governments, states, and levee districts, and finally the Federal government.

28. Although devastating floods have occurred several times during this century, Congressional concern for adequate flood-control measures was most sharply brought into focus during the flood of 1927, termed one of the worst peacetime disasters in United States history. The Mississippi River levees were breached at 13 principal points despite efforts to strengthen them; as a result, 26,000 square miles of land were inundated. The magnitude of the rescue and flood refugee problem was staggering. More than 637,000 people were driven from their homes. The crevasse waters swept so quickly into the lowlands that thousands had to be rescued from rooftops and trees. Although volunteer and government agency workers fought to minimize the number of fatalities, more than 200 lives were lost. Property damage amounted to $236 million (1927).

29. As a result of the flood of 1927, Congress passed the Flood Control Act of 1928, which hastened the placement of control works in the Lower Mississippi Valley. Although many control projects have been completed since 1928, flooding still remains a serious deterrent to the economic and social well-being in many parts of the basin. The current magnitude of this problem was clearly shown by the flood of 1973. Although not as serious as the record flood of 1927, the high water caused nearly $760 million in damages, left thousands homeless for an extended period, and caused 28 deaths. The main line of defense against such disasters in the basin is the Mississippi River and Tributaries Project, authorized in the Flood Control Act of 1928. The design flood for this project has a maximum flow of 2,720,000 cfs at Vicksburg; in comparison, the flood of 1973 had a maximum flow of 1,962,000 cfs. The project is not complete; however, in the absence of the project, the tremendous dollar damages and human suffering experienced in 1973 would have been magnified nearly 18 times.

Streamflow and water supply

30. The Lower Mississippi River Basin is water-rich, in comparison with the other major river basins of the United States. The Mississippi River and its major distributary, the Atchafalaya, discharge an annual

average of 463 million acre-ft into the Gulf of Mexico. These figures include flows passing into and through the basin and those flows generated within the basin; 328 million acre-ft are discharged through the Mississippi delta, and 135 million acre-ft through the Atachafalaya outlet. The major inflow into the basin is from the Ohio and Upper Mississippi Rivers, which collectively input a mean annual flow of 327 million acre-ft into the Lower Mississippi main stem. Additional annual inflows to the basin average 24 million acre-ft from the White River, 30 million acre-ft from the Arkansas River, and 42 million acre-ft from the Red River.

31. In 1970 over 1.8 billion gallons of water were withdrawn each day from basin surface and groundwater sources (Table F2) to meet requirements for four categories of use: municipal, industrial, thermoelectric, and rural domestic. About one of every eight gallons withdrawn was consumed. As the competition among different users for water intensifies and as the basin population and economic growth accelerate, adequate provisions for water supply become increasingly more essential. By 2020, basin water withdrawals will probably be five to six times as large as present, with industry using one of every two gallons.

## Vegetation

32. Prior to the radical land-use changes of the past 200 years, the Lower Mississippi River Basin was almost completely forested. According to Küchler,[6] the natural vegetation of the basin was distributed areally (Figure F6) as follows:

| Map Unit | Vegetation Type | Percentage of Area Covered |
|---|---|---|
| G | Central and eastern grasslands | 9 |
| H | Central and eastern grasslands and forest combinations | 3 |
| J | Eastern broadleaf forests | 27 |
| K | Eastern broadleaf and needleleaf forests | 61 |

Current land-use inventories (1967) indicate that approximately 41 percent of the basin area is now used for cropland, 12 percent for pastures and range, 36 percent for forests, with the remainder being used for urban areas, lakes, airports, etc. (paragraphs 79-82).

## PART II: CULTURAL HISTORY

33. The action of natural forces alone, even without the influence of cultural activities, have had sufficient impact to make the Lower Mississippi and Atchafalaya Rivers major sediment carriers. Upstream settlement and the resulting changes in land use accelerated the erosive processes, thus significantly affecting the suspended-sediment regime and bed-material gradation of the basin. In the following paragraphs, a brief history of exploration and settlement, the development of economic and social trends, and an examination of land-use changes are presented. Emphasis is given to those cultural activities that have had the greatest impacts on the suspended-sediment regime and the bed-material gradation.

### Exploration and Settlement

34. The Lower Mississippi River Basin has been occupied by man for thousands of years. Historic records do not accurately indicate when the first Indians arrived in this basin; however, archeologic evidence strongly suggests that it was over 10,000 years ago. In the early days these immigrants subsisted on hunting and food gathering; their descendants later developed some agricultural practices. European explorers visited the basin beginning in the 1500's. The first French settlement in the basin, Fort St. Pierre des Yazous, was founded by Canadian missionaries in 1698, 15 miles north of present-day Vicksburg, Miss. Another outpost, Fort de la Boulaye or Fort of the Mississippi (founded 1700) was the first French settlement on the Mississippi River, being located one mile north of the present site of Phoenix, La. The first permanent settlement, however, was Natchez, which was founded in 1716. Settlements were made and the population of the basin grew during periods of French, Spanish, and American influence.

#### Indians[1,7-9]

35. The first Indians could have arrived in the basin as early as 15,000 B.C., but more likely 10,000 B.C. Archeologic information is scant over most of the basin, with many of the findings being

reconstructed from house and village features, pottery fragments, and other artifacts. The earliest known identifiable culture is Poverty Point, named for its large and imposing site in West Carroll Parish, La. (in Arkansas-White-Red Rivers Basin). Only limited artifacts from the primitive culture of these early nomadic settlers remain.

36. Agricultural societies were developed around 2000 B.C. The Indians grew corn, beans, squash, and other crops. Because of the varied environmental conditions in the basin, different lifestyles and cultures were established to adapt to these conditions and to exploit the locally available resources in the best possible manner. By the time the Europeans arrived, there were a number of different Indian tribes and linguistic groups. Among these were the Illinois, Quapaw, Chickasaw, Tunica, Ofogoula, Choctaw, Natchez, Chitimacha, the Washa, Chawasha, and Attakapas. Because of the availability of fertile farmland, agriculture had become widespread throughout the basin when the Europeans encountered these Indian groups.

Spanish explorers[4,8,10-12]

37. Christopher Columbus was probably the first European to see the mouth of the Mississippi River, although this has been a matter disputed by historians. The so-called "Admiral's Map" found in the Royal Library of Madrid provides evidence to support the theory that the delta of the river was seen by Columbus on his fourth voyage of discovery. Columbus left Spain in March 1502, touched at Santo Domingo and continued westward toward the Central American coast. The "Admiral's Map," which appears to have been engraved in 1507, shows the passes of the Mississippi River, then called the River of Palms.

38. The first exploration of any significance into the basin was led by Pãmfilo de Navarez. He left Spain with 600 colonists and soldiers, reaching Tampa Bay in April 1528. The expedition then proceeded overland to Apalachee Bay where Navarez and his men constructed several crude sailing craft. After completion of the vessels, they sailed westward along the northern coast of the Gulf of Mexico. On 31 Oct 1528 they entered the waters of the Mississippi River. The strength of the ill-fated expedition was eventually reduced to four. One of the

survivors, Alvar Nunez Cabeza de Vaca, recorded the details of the Navãrez expedition in his "Relacion." De Vaca's "Relacion" was the first positive identification of the waters of the Mississippi River.

39. On 30 May 1539 Hernando De Soto and his entourage arrived in Florida. De Soto had been given the task of locating the Fountain of Youth, but since he was only forty years old at the time, he was much more interested in finding gold than in regaining his youth. His three-year trek took him north into the Ohio River Basin and westward toward the heart of the continent. On 8 May 1541 his expedition reached the Mississippi River. De Soto died on 21 May 1542 near the Indian village of Nilco in what is now Desha County, Ark., and was buried in the Mississippi River. After De Soto's death, Luis de Moscoso assumed command of the expedition. Moscoso's party travelled into southern Arkansas and Texas, crossed the Red River, and then returned to Nilco. Here, they constructed seven brigantines and sailed down the Mississippi River and westward along the Gulf of Mexico, discovering the mouth of the Atchafalaya River on their way to Mexico. After departure of the Moscoso party from the basin there was no European activity for more than a century until the French explorers arrived from Canada.

French explorers and the period
of French control in the basin[4,7,8,10,13-18]

40. The Spanish are recognized as the first Europeans to explore the basin; however, it was the French who made the first serious attempts at settlement. Père Jacques Marquette, a missionary priest, and Louis Joliet, a veteran voyageur, travelled the Mississippi River as far downstream as its confluence with the Arkansas River in 1673. They concluded that this stream flowed into the Gulf of Mexico rather than into the "South Sea" (Pacific Ocean). In 1682 Robert Cavelier, Sieur de la Salle, reached the mouth of the Mississippi and claimed the entire drainage basin of this river for France. He named his discovery "La Louisiane" in honor of King Louis XIV. La Salle had plans to build a series of forts from the Great Lakes to the mouth of the Mississippi, but he was murdered by mutinous members of his crew near the coast of Texas in March 1687 before his dreams were realized.

41. The first settlement in the basin was Fort St. Pierre des Yazous, founded 11 Jan 1698 by four missionaires from Quebec. This post was located on the Yazoo River 15 miles north of present-day Vicksburg. The missionaries estimated the local native population to be 2000.[13]

42. On 24 Oct 1698, the Canadian, Pierre Lemoine, Sieur d'Iberville, left Brest, France, for the Gulf of Mexico. With him were 200 persons, including soldiers and settlers. On 6 Feb 1699 Iberville chose a site on Biloxi Bay (present site of Ocean Springs, Miss.) for his colony. During the construction of a fort at the site, Iberville, his younger brother, Jean Baptiste Lemoine, Sieur de Bienville, and 45 others left the Biloxi settlement to find and explore the Mississippi River. After the fort at Biloxi was completed, Iberville sailed for France on 3 May 1699 to obtain supplies and reinforcement for the infant colony. Bienville continued to explore the Mississippi, where in September 1699, he encountered an English vessel in a bend of the river twelve miles downstream from the present city of New Orleans. The ship, commanded by CPT Lewis Bond, was taking a group of French Huguenots from Carolina to establish an English colony in Louisiana. Bienville convinced the English captain that the French had already settled the area and that any intruders would be driven away by force. The young Frenchman's bluff succeeded. CPT Bond raised anchor, turned his vessel, and headed back out into the Gulf of Mexico. From that time on, the bend was known as "English Turn."

43. Iberville returned to Biloxi on 6 Jan 1700 with two ships and more soldiers and settlers. When he learned of the encounter between Bienville and CPT Bond, he was convinced that there was a serious threat of English encroachment in the Mississippi Valley. He sent Bienville by way of Lakes Borgne, Pontchartrain, and Maurepas to the country of the Bayougoulas (vicinity of present-day Plaquemine, La.) for guides, while he and fifty Canadians ascended the Mississippi River from its mouth. Iberville met Bienville 60 miles upstream from the mouth. Near this meeting place they began to build a fort that was called Fort of the Mississippi or Fort de la Boulaye. The site was located on the left bank of the Mississippi, one mile north of the present site of Phoenix, La.

Fort de la Boulaye was abandoned in 1701, because it was subject to flooding during periods of high flow.

44. John Law, an enterprising Scotsman, convinced Philippe, Duc d'Orléans, the regent of France acting during the minority of Louis XV, that he could run the Louisiana colony at a profit. Law agreed to provide 6000 settlers and 3000 slaves. He organized the Company of the West on 6 Sep 1717 (reorganized in 1719 as the Company of the Indies) and sold shares throughout Europe. Law succeeded in bringing a number of German and some French settlers to the basin concessions granted by his company in the early 18th Century; these concessions were scattered throughout the southern basin in the present states of Louisiana and Mississippi.[15]

45. In September 1717, John Law's Company of the West decreed that a town should be established on the Mississippi River, about three leagues* upstream from the mouth, and that it should be called New Orleans. Bienville, who was struggling to keep the colony alive, proposed instead that the new settlement be located at its present site between Lake Pontchartrain and the Mississippi, such that it would be accessible by water from either side. Bienville reported in June 1718, that he was working on the construction of New Orleans, but two years later a traveler noted that the so-called "city" consisted of a hut roofed with palmetto leaves. About a month later, another report said that there were three houses and a warehouse on the site. Fever, floods, and fires made Bienville's task a difficult one, but by March 1721, the section of the city that is today known as the "Vieux Carré" or "French Quarter" was laid out, and a census of the inhabitants of the city claimed a population of almost 250. In 1722 New Orleans was made the capital of the colony.

46. A number of settlements were founded in other parts of the basin in the early 18th century. Most of these grew around military posts. Among the more significant ones were Natchez (1716), Baton

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* In the language of the early 18th century French, one league ("lieu") was probably equal to between 3.0 and 3.5 U. S. statute miles.

Rouge (1719), and Pointe Coupée (1720). Natchez grew around Fort Rosalie. Baton Rouge began as a small military post near the boundary between the Bayougoula and Houma tribes. This boundary was marked by a tall red pole that the Indians called "Istrouma" (meaning "Red Stick," thus the origin of the name "Le Bâton Rouge" used by the French). Pointe Coupée was located near False River in present-day Pointe Coupée Parish, La.

47. On 28 Nov 1729, the residents around Fort Rosalie at Natchez were savagely attacked by the Natchez Indians, and according to a report by Père F. Philibert, the missionary assigned to the post, a total of 144 men, 35 women, and 56 children were massacred.[17] On 30 December of the same year the Yazoo Indians killed all but four women and five children in the vicinity of the oldest basin settlement, Fort St. Pierre des Yazous. Needless to say, there was now great anxiety throughout the entire colony, and the city of New Orleans fortified itself against the threat of Indian attack.

48. Bienville knew that if New Orleans was to survive, the city must also be protected from high flows. One of Bienville's engineers, Sieur Blond de la Tour, suggested that the existing network of drainage canals should be interconnected and that a levee be built to protect the area from flooding. By 1727 New Orleans had a levee 5400 ft long, 3 ft high, with a top width of 18 ft. The length of the structure was extended rapidly, as the levee lines kept pace with the establishment and growth of settlements. By 1735 levees extended along both banks of the river for a distance from 30 miles upstream to 12 miles downstream from New Orleans.

49. When the French colonists came to the Lower Mississippi Valley, they found navigation difficult in all the passes at the mouth of the Mississippi River. In 1723, one of the colony's master carpenters proposed to dredge the bar at the entrance to the Mississippi, declaring that he could deepen it to 38 ft. Although his plan was not approved, in 1729 a colonial official reported that the channel had been deepened from little more than 12 ft to 17 ft and would soon be navigable for all kinds of French vessels. The channel that the French

navigators used was the Southeast Pass, a branch of Pass a Loutre. They built a fortification on the bank in the pass and called it "Balize," a name derived from the French word for "beacon."

50. Although Louisiana continued to grow, Louis XV looked with disdain upon the colony especially after the losses the French treasury suffered from John Law's scheme. France had become involved in a costly war with England, and the monarch felt his treasury could no longer bear the burden of the Louisiana colony.

Spanish control of the basin[7,8,10,17]

51. By the 1762 secret Treaty of Fontainbleau, France ceded all territory west of the Mississippi River plus the "Isle" of New Orleans* to Spain, and by the Treaty of Paris (1763), England received the eastern Mississippi River Basin (except New Orleans) and Canada. Spain deeded her holdings in East and West Florida to England. England took posession of her territory almost immediately. This caused many Frenchmen who were living east of the Mississippi River to migrate to the west of this stream, including those in Mobile, Baton Rouge, Natchez, and in the Illinois Country. England realized the importance of her post at Manchac (located on Pass Manchac between Lakes Pontchartrain and Maurepas, northwest of New Orleans). Four months out of the year goods could travel to Manchac from the Gulf of Mexico via Lake Pontchartrain or from the Mississippi via Bayou Manchac** and the Amite River (collectively called the Iberville River) and Lake Maurepas. England planned to divert much of the trade that was bound for New Orleans to Manchac.

52. Spain was slow to take possession of her new colony. The Treaty of Fontainbleau had been ratified 2 years before the residents of Louisiana were formally notified. A number of the leading citizens in New Orleans led by Nicolas Chauvin de Lafrénière, Attorney-General of the colony, attempted to petition King Louis XV to reconsider his

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* The "Isle" included all the area bounded on the south and west by the Mississippi River, on the east by the Gulf of Mexico, and on the north by Lake Pontchartrain, Pass Manchac, Lake Maurepas, the Amite River, and Bayou Manchac.

** In 1826 Bayou Manchac, a former distributary of the Mississippi, was severed artifically by a levee constructed across the confluence.

action. Jean Milhet, a wealthy merchant, was chosen to present the message to the king. The monarch, however, chose to receive neither Milhet nor the message he was delivering to Paris. At the time Milhet was in France, Jean Jacques-Blaise d'Abbadie, Governor of the Louisiana colony, died while in office, and CPT Charles-Philippe Aubry assumed the authority as acting Governor because he was the ranking military officer in the city. The ruthless Aubry continued to act as Governor even after Spanish apointee, Don Antonio de Ulloa, arrived on 5 May 1766. Through Aubry, Ulloa announced that the colonial policy of Spain would be implemented in Louisiana and that the maritime trade of the colony would be restricted to six Spanish cities. This action caused angry mobs of colonists to demonstrate in favor of French products and in disapproval of those of Spain. In 1768 the colonists literally drove Ulloa out of Louisiana and back to Spain (the first such revolt by colonists in the New World against a European power).

53. In Spain, Ulloa filed a report of what had happened in New Orleans. The Spanish crown reacted by sending Don Alexander O'Reilly to the colony, whose duty as military commander would be to insure that the leaders of the rebellion were punished. In 1769 O'Reilly sent Juan Kelly and Eduardo Nugent to the various posts and settlements in the colony that had been established by the French to obtain oaths of allegiance to Spain from the colonists and to take a census of these colonists and their livestock. O'Reilly appointed Luis de Unzaga y Amerzaga as Governor of Louisiana in 1772. Unzaga won great favor with the citizenry by "...his self-imposed blindness that permitted a great deal of illegal trade between the colony and the British in West Florida."[10] The British post of Manchac was easily accessible by land or by water. As a result of this illegal trade, many British goods found their way into Spanish Louisiana.

Spanish and American
control of the basin[8,10,19]

54. Spain officially entered the American Revolution as an ally of France in 1779. Bernardo de Gálvez, the Governor of Louisiana, launched attacks and successfully took a number of British posts in West Florida.

England responded by attacking American and Spanish posts. This conflict was ended by the Treaty of Paris (1783), with the United States gaining title over all lands north of Florida, south of Canada, and east of the Mississippi. Spain held all lands west of the Mississippi River plus reacquired Florida, which meant Spanish control of both banks of the Mississippi River from Natchez downstream to the Gulf of Mexico. The Spanish now had to contend with a new and independent neighbor, whom she feared would have designs on her holdings in Louisiana.

55. During Spanish control of Louisiana, there were a number of new settlements started in the Lower Mississippi River Basin. Many of these settlements were extensions of early outposts that had been established during the period of French control. Other settlements had been previously populated by the Indians. To induce settlement of the basin, Spain offered liberal land grants. Some of the larger grants were in present-day Iberville, St. Landry, St. Martin, and St. Mary Parishes in Louisiana. Spain hoped that by establishing settlements in sparsely populated land that she could secure a better hold on Louisiana.

56. The Treaty of San Lorenzo el Real was signed 27 Oct 1795, by the United States and Spain. This document adjusted the boundary between West Florida and the United States to 31 deg north latitude, in line with the present boundary of Louisiana and Mississippi that runs east-west between the Mississippi and Pearl Rivers. This meant that Americans would now be living on the Mississippi River downstream from the mouth of the Yazoo River to the new boundary. On 7 Apr 1798 the United States Congress created the Territory of Mississippi, part of which was known as the Natchez District. The most important fortification in the Natchez District was Fort Nogales, which was built in 1791 near the confluence of the Yazoo and Mississippi Rivers (present-day Vicksburg). The only basin settlement of any significance in the new territory, however, was Natchez.

<u>American control of the basin</u>[4,8,14,17,20]

57. In 1800 the Spanish crown returned the Louisiana colony to France by the secret Treaty of San Idelfonso. Immediately after this treaty had been ratified, Napoleon realized that he needed resources for

another war with England; therefore, he sold the entire 875,000 square miles of the Louisiana colony (i.e., the Louisiana Purchase) to the United States. Napoleon's representative for the transfer did not arrive in Louisiana until 30 Nov 1803, seven months after the purchase. Twenty days later the United States flag was hoisted in New Orleans. In 1819, after the acquisition of West Florida, the period of discovery and settlement had come to a close. The Mississippi River was now entirely within the territorial limits of the United States. The lower river valley was comparatively well settled especially in its southern areas where a levee system for flood control had been established. River commerce flourished, with a consequent need for navigation improvement.

58. Territories were carved out of the Lower Mississippi River Basin, and out of these territories, states were admitted to the Union. Parts of six states were taken from the area comprising the basin. By 1836 all basin states had been admitted to the Union in the following order:

| State | Date of Admission | Order of Admission |
|---|---|---|
| Kentucky | 1 Jun 1792 | 15th |
| Tennessee | 1 Jun 1796 | 16th |
| Louisiana | 30 Apr 1812 | 18th |
| Mississippi | 10 Dec 1817 | 20th |
| Missouri | 10 Aug 1821 | 24th |
| Arkansas | 15 Jun 1836 | 25th |

## Economic and Social Trends

59. The first permanent settlers in the Lower Mississippi River Basin--both Indians and whites--were farmers; thus much of the early development of commercial centers was directly attributable to agricultural activities. Gradually other industries grew along with the transportation networks and urban centers necessary to support them. The following paragraphs deal with the development of agriculture, commerce and industry, transportation, and population and urbanization in the basin.

Agriculture[1,7,10,14,18]

60. The first farmers of the basin were probably the Poverty Point Indians; however, their agricultural practices were not well organized. During the French colonial period there was little progress made in agriculture; many foodstuffs had to be imported from France or other French colonies (e.g. Illinois Country or the West Indies). The limited numbers of personnel at the military posts made farming difficult. Although the basin was fertile, much of the land had to be drained before it could be cultivated. It was during the time of John Law's Company of the West that the first serious attempts were made to make the basin agriculturally self-sufficient.

61. During the 18th century indigo, tobacco, cotton, and rice were grown. Cotton was the major crop; however, until Eli Whitney invented the cotton gin in 1793, cotton processing and spinning was a slow and laborious process. With the availability of slave labor for planting, cultivating, and harvesting the crop, cotton flourished in the fertile lands of the basin. As a result, there was much land clearing, and many of the farms were subjected to a one-crop culture with little thought given to depletion of nutrients or to soil conservation. In 1751 sugar cane was introduced from Santo Domingo, and in 1795 Etienne de Boré performed the first successful granulation of sugar on his plantation (now Audubon Park) near New Orleans.

62. In 1970, there were over 100,000 farms in the Lower Mississippi Basin. Approximately 70 percent of 1970 total gross farm income was derived from the marketing of crops--primarily soybeans and cotton. Since 1970, there has been a dramatic decline in the number of small farms in the basin; however, it is anticipated that the rate of decline will subside in future years. The number of farms in the larger size groups is expected to increase to better accommodate modern farming methods and to reduce total production costs and increase net returns. Although there are currently many more farms in the smaller-size groups, the farms in the larger-size groups comprise a larger percentage of the total farmland base and produce the larger share of crops and livestock.

63. Forests and forestry products have historically played an

important role in the development of the basin. Prior to 1959, the accessibility of forest land, the availability of local markets, and the presence of an excellent road and river system all contributed to the rapid development of forest resources. The productivity of forest lands in the basin is generally regarded as among the highest in the United States. Between 1949 and 1959, there was a slight increase in total forest acreage. Since 1959 forest acreages have steadily declined, and forests are becoming increasingly restricted to areas where flooding, poor drainage, and soil conditions make the land unsuitable for other uses.

<u>Commerce and industry</u>[1]

64. Commerce in the Lower Mississippi River Basin had its origins in the colonial days. The Spanish explored the gold potential of the basin in the 1500's; however they found very little. The French interests centered mostly around fur trapping and trading. There was some agricultural activity during the colonial era, but most of this occurred many years after the French period.

65. Major economic trends in the Lower Mississippi River Basin during the past four decades have focused on the shift in labor from agriculture to other types of employment. During the 1930's, about 50 percent of the labor force worked on farms or plantations; by 1970 the ratio had declined to 10 percent, and it is expected to fall to 2-1/2 percent by 2020. Slightly more than one-third of the population of the basin was employed during the 1960's. This proportion gradually will increase so that by 2020 the employment participation rate will reach 40 percent, as compared with 41 percent for the Nation. Offsetting the decline in agricultural activities are major expansions in manufacturing and other areas. Food processing is the only manufacturing activity showing a noticeable employment decline.

66. Earnings per worker for the region were 20 percent lower than earnings for the remainder of the Nation during 1968. Future changes in employment characteristics and greater urbanization will bring the regional average up to 90 percent of the national average by 2020. The lower per-worker earnings in the basin reflect the fact that earnings are higher in large cities than in small cities, and are higher in urban

than in rural areas. Thus, the absence of a megalopolis and a greater dependence on agriculture in the basin have resulted in low average per-worker earnings.

Transportation[1,4,19-24]

67. The Indians and later the French voyageurs travelled the streams of the basin in canoes; however, the travel of Spanish explorers was mostly overland. The French found that a pirogue was a more suitable craft for travel on the bayous than the canoe. The pirogue was constructed by hollowing out a log (usually cypress) and propelled by "poleing," a technique the French learned from the Indians. The pirogue was soon found to be a very effective means of transportation in the very shallow and sluggish watercourses of the basin.

68. The earliest commercial use of the river by Europeans was in 1705 when the first cargo of hides floated downriver by canoe from French settlements in the Wabash Country (Ohio River Basin). Flat-bottomed boats soon appeared on the river, but the growth of trade between New Orleans and the upper river settlements called for more reliable craft. The keelboat, which could carry 80 tons of cargo, was developed to meet this need. Despite great difficulties, both from treacherous stream currents and from hostile Indians, river transportation had become an integral part of the economic base of the basin by 1745.

69. The invention of the steamboat in the early nineteenth century brought about a revolution in river commerce. The first steamboat to travel the Mississippi was the "New Orleans." Built in Pittsburgh in 1811 at the cost of $40,000, she was a 116-ft-long side-wheeler that weighed 371 tons. On her maiden voyage, the "New Orleans" was caught in a series of tremors known as the New Madrid Earthquake, probably the worst nonvolcanic earth shock in American history. Nevertheless, the New Orleans continued downriver on the nightmarish trip, becoming the first steamboat to negotiate the Lower Mississippi.

70. The steamboat not only hauled freight, but also provided comfortable accommodations for passengers; even more important, it could travel upstream almost as easily as downstream. In 1814 only 21 steamboats had arrived in New Orleans; in 1819 there were 191; and by 1833

more than 1,200 steamboat cargoes were unloaded. Before the invention of the steamboat, a trip from Louisville to New Orleans often required 4 months. In 1820 the trip was made by steamboat in 20 days. By 1838, the same trip was being made in 6 days.

71. The packet boat brought about a phenomenal increase in Mississippi River traffic. In 1834, there were 230 packets on the river; by 1849, there were approximately a thousand with a total cargo capacity of 250,000 tons. The packet continued to be the principal means of transportation on the Mississippi until the latter part of the nineteenth century, when a major portion of the commerce began to be diverted to the expanding railroads.

72. The present navigation system of the basin includes a number of streams besides the Mississippi and Atchafalaya Rivers. These include Big Pigeon and Little Pigeon Bayous, the Gulf Intracoastal Waterway, the Innerharbor Navigation Canal, the Waterway from Empire, La., to Gulf of Mexico, the Wolf River (Memphis Harbor), and the Yazoo River. Freight and passenger traffic during calendar year 1977 for the Lower Mississippi River Basin and connecting waterways are presented in Table F3.

73. The prehistoric Indians used numerous basin trails when they searched for food or traded with their neighbors. As the settlement of the basin progressed, the early pioneers found it necessary to construct new roads to expedite the movement of settlers and goods. An 1806 map[19] shows roads connecting New Orleans with Baton Rouge (River Road), Biloxi, and areas in present-day St. Bernard Parish. There was also a road paralleling the right bank of the Mississippi from New Orleans to Donaldsonville and another along the left bank of the river between Baton Rouge and present-day Vicksburg running through Bayou Sara, Fort Adams, Miss., and Natchez. The Old Spanish Trail ran from Opelousas to a right-bank landing opposite Bayou Sara; in addition, roads connected both Donaldsonville and New Iberia with the Lower Atchafalaya.

74. The Natchez Trace, a trail used by the Indians between Natchez and Nashville, made its first appearance on a European map in 1733. Beginning around 1785, the Trace was used by traders returning from New Orleans after floating their goods downriver. Spanish records

indicate that 240 persons used the trail in 1790.[24] This number had grown to 10,000 travelers by 1810. The Natchez Trace continued to be used heavily until 1819 when the steamboat came into widespread use on the Ohio and Mississippi Rivers.

75. The Lower Mississippi River Basin is now served by an excellent system of highways, railroads, pipelines, and airlines. This vast network handles transportation within the basin, and provides connections to points outside the basin.

Population and urbanization[1,25-27]

76. Prior to the arrival of the European explorers, the Lower Mississippi River Basin was occupied by the Indians in a number of different settlements. Population figures for the Indians are difficult to estimate; however, there were probably several thousand when the Spanish explorers arrived. Many of the early French settlements grew around military posts. Although a number of these original settlements no longer exist, others have grown into thriving cities. A November 1721 census of the inhabitants of "New Orleans and its Environs" taken by the French[25] shows that there were 1,266 inhabitants.

77. The population of the basin grew during the French colonial period as a result of John Law's ambitious schemes. Many important concessions were granted for the purpose of settlement and development. Although several basin cities and towns were established during the periods of French, Spanish, and American jurisdiction, the greatest settlement influx occurred after the Louisiana Purchase and the acquisition of West Florida by the Adams-Onis Treaty of 1819. Table F4 shows, in chronological order, selected basin cities and their dates of settlement.

78. In 1975 there were four Standard Metropolitan Statistical Areas (SMSA's) wholly or partially within the basin as follows:

| State(s) | SMSA |
|---|---|
| Louisiana | Baton Rouge<br>New Orleans |
| Mississippi | Jackson |
| Tennessee-Arkansas-Mississippi | Memphis |

Table F5 provides basin population statistics for selected years between 1900 and 2020. Census data are generally collected by states, counties, or other political subdivisions and not by river basins; thus, it is often difficult to obtain direct population figures for a basin; however, reliable information can usually be obtained by overlaying basin boundaries on a population base developed from available census data. The population has increased steadily in most parts of the basin except in the St. Francis and Yazoo Subbasins. Both of these subbasins, however, are expected to gain in population after 1980. In the next several years, the population of the SMSA's is expected to increase, with much of the increase being attributable to expanded market areas and diversification of industry. The rural population will probably decrease as many leave the farm for work in the city.

## Land-Use Development

79. Land use and land-use change with respect to time play significant roles in defining the characteristics of a basin's sediment regime and bed-material gradation. Quantitative land-use information (i.e., maps or statistical data) is difficult to obtain on a basin-wide basis especially for different time frames. Many Federal, state, regional, and local agencies are engaged in the process of mapping land use, but the variations in methods used to obtain these data, their reliability, and even the choice of parameters used to quantify land use are widely diversified.

80. In the six states comprising the Lower Mississippi River Basin, land-use mapping is in progress. The following typical land-use products have been published:

a. Arkansas. The USDA Soil Conservation Service (SCS) published a Conservation Needs Inventory (CNI)[28] in 1969 containing land-use data by counties.

b. Kentucky. Some Landsat mapping is being done for various agencies; however, mapping is not statewide. A CNI[29] was completed by the SCS in 1970.

c. Louisiana. The U. S. Geological Survey (USGS) through its Land Use and Data Analysis (LUDA) program has produced land-use maps,[30] keyed to the USGS 1:250,000-scale topographic maps, covering the state of Louisiana. There is a tabular summary[31] by parishes of the area for each classification used in the LUDA maps. A CNI[32] was published in 1969.

d. Mississippi. Land-use photomaps[33] for all the counties in Mississippi have been compiled from the National Aeronautics and Space Administration Earth Observation Aircraft Program, high altitude photography. A CNI[34] completed by the SCS in 1970 is an additional source of land-use data.

e. Missouri. State agencies and universities in Missouri have prepared reports[35,36] describing techniques for mapping land use with Landsat and other remote imagery. In addition the SCS published a CNI[37] in 1970.

f. Tennessee. The SCS completed a CNI[38] in 1971.

81. Land-use data for the six states[28-38] have been mapped by political units rather than by watershed boundaries. The CNI's provide land-use data by county for 1958 and 1967. Data for years prior to 1958 are available by county from Federal decennial and agricultural censuses. Both the CNI's and the census data must be adjusted such that they are compatible with the watershed boundaries rather than with the established political boundaries. The exception to this are the data for 1967 stored on magnetic tape at the Iowa State University Statistical Laboratory, Ames, Iowa, that can be retrieved by either basin unit or political entity.

82. The following categories taken from the CNI's have been used to quantify land-use change in the Lower Mississippi River Basin:

a. Cropland. Irrigated and nonirrigated land that has been tilled within the last five years, including land planted in hay crops or used for orchards and vineyards.

b. Pasture and rangeland. Pasture is defined as land planted in introduced grasses primarily for livestock consumption. Rangeland includes all natural grazing lands and lands seeded with a mixture of native climax-adapted grasses for grazing use; cropland abandoned for five years where the intended use is grazing; and wild hay, native hay, or rangeland meadow.

c. <u>Forest.</u> Commercial and noncommercial woodlands and windbreaks of one acre or more; U. S. Forest Service and other Federal lands containing 10 percent (crown coverage) or more trees capable of producing timber or wood products or of exerting an influence on the water regime, and grazing woodlands.

d. <u>Other land.</u> Farmsteads, roads, feedlots, ditch banks, fence and hedge rows, rural nonfarm residence, other rural lands not suited for agriculture (e.g., marshes); Federally owned land not leased for grazing or for forestry; cities, towns, and built-up areas more than 10 acres in size; industrial sites, railroads and railroad yards, cemeteries, airports, golf courses, parks and recreational acres; institutional and administrative sites; ponds, lakes, reservoirs, and other waterbodies more than two acres in size; and any other areas that do not meet the requirements of a, b, or c.

Land-use data for the Lower Mississippi River Basin for four selected years are provided in Table F6 by the categories defined above;* the appropriate documentation of source material for each year is given below:

| Year | Reference(s) |
|---|---|
| 1860 | 39 |
| 1910 | 27 |
| 1935 | 40 |
| 1967 | 28, 29, 32, 34, 37, 38 |

* Data for 1860 were collected for only three categories: cropland, pasture and range, and forest and other land (Table F6).

## PART III: CHARACTERIZATION OF SUSPENDED-SEDIMENT REGIME

83. Average sediment yields over the Lower Mississippi River Basin (869 tons/mi$^2$/yr) are greater than over the remainder of the Mississippi River drainage with the exception of yields in the Arkansas-White-Red River Basin (1227 tons/mi$^2$/yr). Erosion in the Lower Mississippi River Basin causes annual financial losses in excess of twelve million dollars (1974).[1] Sixty-five percent of these losses result from sheet erosion, 21 percent from gully erosion, 10 percent from streambank erosion, and 4 percent from roadbanks.

84. The amount of sediment discharge at any location within a river system is a function of many variables, which fall into two general categories: the characteristics of the drainage basin, and the stream morphology and cultural constraints through the reach in question. Important drainage basin characteristics include physiography and geology (paragraphs 10-13), soils (paragraph 14), climate (paragraphs 15-19), hydrology (paragraphs 20-31), and vegetation (paragraph 32). In addition, stream width, velocity, slope, temperature, and turbulence, bed and bank particle size and type, and control conditions both upstream and downstream of the reach of interest must be considered when developing an understanding of the suspended-sediment regime.

85. Major changes in land use (paragraphs 79-82) have encouraged an increase in soil losses over the Lower Mississippi River Basin. Under present conditions, estimated annual sediment yields for the basin range from 1029 tons per square mile in the Western Tennessee Subbasin to 157 tons per square mile in the Atchafalaya River Subbasin (Table F7). Soil losses in the six subbasins are discussed below.

86. The Atchafalaya Subbasin began to take its present form during the 15th century when an enlarging loop of the Mississippi, later called Turnbull's Bend, broke into the drainage of the Red River.[16] When the first Europeans arrived, they found the Atchafalaya as a well-defined distributary of the Mississippi flowing out of Turnbull's Bend a few miles south of the Mississippi-Red confluence. In 1831, the bend was cut off under the direction of Henry M. Shreve. The abandoned bend,

whose arms were known as Upper and Lower Old River, showed the customary tendency to silt up. Both the channels would eventually have become permanently filled if left to themselves, and the Red and Atchafalaya would have formed a single river running parallel to the Mississippi; however, the lower channel was dredged to maintain navigation and trade between the river systems.

87. Flow through Old River was reversible according to the relative stages of the Mississippi and Red. During the period 1885-1889 the Mississippi River Commission (MRC) built three sill dams on the Atchafalaya, to retard flow from the Mississippi into the Atchafalaya; however, at the same time the MRC continued to dredge Old River at the urging of steamboat interests. By 1940 the Atchafalaya was providing a river route to the sea with a three-to-one advantage in bed slope over the Mississippi main-stem channel downstream from the Old River confluence. Any need to dredge Old River had long since ceased. The Atchafalaya channel was rapidly enlarging, while the Mississippi just downstream from Old River was beginning to fill--indicating a loss of cross section as a result of the decrease in current velocity caused by the Old River diversion. The last year in which significant eastward flow was observed through Old River was 1942, when the current moved toward the Mississippi for a period of nine days.

88. In 1953 a team of geologists directed by Dr. Harold N. Fisk reported to the MRC that the diversion would reach a critical stage during the 1965-1975 decade, when 40 percent of the flow of the Mississippi would be passed into the Atchafalaya and deterioration of the main channel would become irreversible.[20] This study resulted in the Congressional legislation of 3 Sep 1954 that provided for control structures at Old River (paragraph 4). Congress authorized an overbank structure to control the passage of floodwater into the Atchafalaya, a low sill structure in a dredged channel paralleling Old River to regulate flow during periods of low water, and a navigation lock to make the Red and Atchafalaya Rivers accessible to traffic from the Mississippi. When this work was completed in 1963, the mouth of Old River was sealed off.

89. Although the Atchafalaya Subbasin is areally the smallest of the subbasins in the Lower Mississippi River Basin and has the lowest average annual sediment yield, its waterways pass nearly 40 percent of the total suspended-sediment load of the Mississippi River Basin to the Gulf of Mexico. The Red River contributes forty million tons annually to the load of the Atchafalaya, while over sixty million tons of the annual suspended-sediment load of the Mississippi River is passed into the Atchafalaya via the Old River Outflow Channel. Only 9.3 percent of the land area in the subbasin is affected by erosion (Table F8), with the majority of this soil loss attributable to sheet erosion.

90. Approximately two-thirds of the land area of the Big Black-Homochitto Rivers Subbasin is affected by erosion (Table F8), of which 69 percent is attributable to sheet erosion, 28 percent to channel and gully erosion, and 3 percent to roadbanks; 1432 miles of streambank are actively eroding. The average annual sediment discharge of the Big Black into the Mississippi is 908,000 tons, with the Homochitto contributing an additional 515,000 tons. Damages in the subbasin due to erosion are $1,540,000 annually (1974). Approximately 60 percent of the damages are in the Big Black River drainage and 17 percent in the Homochitto River Valley.

91. Because of current and anticipated static land use in the Mississippi River Main Stem Subbasin, no changes in areal erosion rates are likely. Currently, only 2.4 percent of the land area in this subbasin is affected by erosion, most of which is attributable to sheet erosion. Main-stem streambank erosion was a serious problem prior to the implementation of stabilization programs; however, the placement of many spur dikes and articulated concrete revetments have measurably reduced bank failures.

92. Approximately 18 percent of the land area in the St. Francis River Subbasin is affected by erosion. Of the total soil loss, 65 percent results from sheet erosion, 18 percent from gully and channel erosion, and 16 percent from roadbanks. There are 559 miles of streambanks that are actively eroding. The average annual suspended-sediment contribution of the St. Francis to the Mississippi River main stem is

1,157,000 tons. The annual damages from subbasin erosion are approximately one-half million dollars (1974). The L'Anguille River (a tributary to the St. Francis) drainage, has the highest rate of sediment yield in the subbasin, with most of the annual 16,768 tons per square mile coming from the alluvial sands of the Crowley's Ridge area. The suspended-sediment contribution of the L'Anguille River to the St. Francis River represents 42 percent of the contribution of the St. Francis to the Mississippi main stem.

93. Highly erosive silty uplands cover a large portion of the Western Tennessee Subbasin. More than 55 percent of the land area is affected by erosion, which is the second highest percentage in the Lower Mississippi River Basin (Table F8). Of the total soil loss, 61 percent results from sheet erosion, 36 percent from gully and channel erosion, and 3 percent from roadbanks. There are 2,877 miles of streambank affected by erosion. The average annual suspended-sediment contribution to the Mississippi main stem by major tributaries located in this subbasin are: Obion River, 2,804,000 tons per yr; Hatchie River, 762,000 tons per yr; Loosahatchie River, 513,000 tons per yr; and the Wolf River, 633,000 tons per yr. The annual damage resulting from soil erosion in the subbasin is $7,728,000 (1974). The majority of this damage is in the Obion River drainage.

94. Approximately 38 percent of the land area in the Yazoo River Subbasin is affected by erosion. Of the total soil loss, 71 percent results from sheet erosion, 26 percent from gully and channel erosion, and 3 percent from roadbanks. There are 2767 miles of streambank affected by erosion. The estimated average annual suspended-sediment load at the mouth of the Yazoo is 4,244,000 tons, all of which is passed into the Mississippi River main stem. The annual damage resulting from soil erosion in this subbasin is $2,723,000 (1974). The soils in the upland areas are inherently highly erosive and thus movement of material towards lower elevations continues to occur. This results in degradation of soils and sterile overwash in the lower more productive alluvial valley.

## Cultural Influences on Suspended-Sediment Regime

95. Flood control is, and has historically been, the primary catalyst in the economic and physical development of the Lower Mississippi River Basin. Without flood control the basin could not sustain its present population, and those residing in the alluvial valley would be under the continuous threat of natural disaster. The man-made changes in the Mississippi River flow regime over the past two centuries were designed to provide flood control and to improve navigation, and in turn, have significantly impacted on suspended-sediment regime of the lower main stem. The history of these changes and current impacts are discussed below.

### Historic improvements in the Lower Mississippi River Basin

96. The importance of flood control was recognized immediately by engineers who accompanied the first settlers into the basin.[41] When Bienville founded the city of New Orleans in 1718, de la Tour, his engineer, opposed the location of the city at the selected site because he knew that the settlement would be periodically flooded by the Mississippi. Bienville overruled this objection, so de la Tour undertook the construction of the first levee system to be erected on the Mississippi. The work was completed in 1727 (paragraph 48).

97. The levee system was extended upriver as settlements developed along the Mississippi. By 1735, the levee lines on both sides of the river stretched from 30 miles upstream from New Orleans to 12 miles downstream from that city. In 1812, when Louisiana was admitted to the Union, the levee system had been extended to Baton Rouge on the left bank and to the vicinity of Morganza, 40 miles upriver from Baton Rouge, on the right bank. In spite of several damaging floods, levee construction continued, and by 1844 the levee system was continuous (except for a gap at Old River) from 20 miles below New Orleans to the mouth of the Arkansas River on the right bank and to Baton Rouge on the left bank. Many isolated levees had also been placed in the lower part of the Yazoo Subbasin. Efforts thus far to control Mississippi River floods had been

almost entirely local in nature, with the expense of constructing this system borne by those who owned land fronting the river.

98. By the beginning of the nineteenth century, the potential for river commerce and the ever-present threat of flood made the need for improvements along the Lower Mississippi more apparent. In 1820 Congress began its long history of influencing the economic development of the basin by authorizing the expenditure of $5,000 for a navigation study of the Ohio and Mississippi Rivers by the U. S. Army Corps of Engineers (CE).

99. As a result of the Swamp Acts of 1849 and 1850, Congress granted to the basin states all unclaimed swamp and overflowed lands within their boundaries. Under the provisions of both acts, funds accruing from the sale of these lands were to be applied to the planning and placement of drainage, reclamation, and flood-control projects. Louisiana, Mississippi, Arkansas, and Missouri organized sales offices and appointed commissioners for the construction of levees; however, this attempt to implement effective flood protection failed primarily because of the lack of coordination of the work among the different states and districts.

100. Pursuant to an Act of Congress, in 1850 the Secretary of War directed Mr. Charles Ellet, Jr., an engineer, to make a survey and to prepare a report on the Mississippi and Ohio Rivers directed toward the development of plans for flood prevention and navigation improvement. Ellet stated in his report that the floods in the alluvial valley of the Mississippi River would increase in frequency and extent with more widespread cultivation and the extension of the levee system. His proposals for the control of Mississippi floods included the prevention of cutoffs, the enlargement of natural river outlets through Bayou Plaquemine and the Atchafalaya River, the creation of an artificial outlet through Lake Borgne and improvement of the levee system especially downstream from the mouth of Red River. As his principal flood-control measure, however, Ellet strongly advocated the construction of a system of headwater reservoirs on the Upper Mississippi River and its principal tributaries.

101. The need for more substantial Federal participation in the

improvement of the Mississippi for flood control and navigation was generally recognized by 1879. The necessity for coordination of engineering operations through a centralized organization was also apparent. On 28 Jun 1879 Congress authorized the formation of the MRC which had as its assigned duties

> "...to take into consideration and mature such plan or plans and estimates as will correct, permanently locate, and deepen the channel and protect the banks of the Mississippi River; improve and give safety and ease to the navigation thereof; prevent destructive floods; promote and facilitate commerce, trade, and the postal service..."[20]

Levee work was begun by the MRC in 1882, marking the beginning of the actual construction of a coordinated levee system for the Lower Mississippi River. By 1906, the operations of the MRC were well advanced. Navigation in the lower reaches of the river had been improved by dredging. Bank protection techniques by means of heavy willow mattresses had been successfully developed, and extensive levee work was being carried on below Cairo, Ill. Flood-control benefits were only incidental, however. Although the law creating the MRC required it to prepare plans to prevent destructive floods, until 1917 the appropriation acts restricted levee construction and repair to such work that was considered a part of the navigation-improvement plan.

Mississippi River
<u>and Tributaries Project</u>[2,42,43]

102. The flood of 1927 was the most disastrous in the history of the Lower Mississippi River. An area of 26,000 square miles was inundated. The total length of levee breached along the main stem exceeded five miles. Cities, towns, and farms were flooded, destroying crops, and paralyzing industry. Property damage amounted to $276 million; 214 lives were lost, and 637,000 persons were displaced. Railroad transportation was disrupted, and only one east-west rail line was operating downstream from Cairo.

103. The 1927 flood forced a reappraisal of the "levees only" philosophy of flood control. President Calvin Coolidge directed the MRC to study the special problems to be solved as part of a comprehensive plan

for Mississippi River flood control, charging MG Edgar Jadwin, Chief of Engineers, to prepare a report on the findings of the study. The report submitted by Jadwin became known as the Jadwin Plan. This plan was adopted as the basis for the Flood Control Act of 15 May 1928, with the long-range objectives being the control of a much greater flood than had formerly been thought possible, and limiting the amount of floodwater carried in the main stem to a safe capacity. The plan provided for the following:

- a. Construction of lateral floodways to pass surplus main-stem flow.
- b. Placement of a controlled spillway at or near New Orleans.
- c. Raising and strengthening the levees between Cape Girardeau, Mo., and Head of Passes.
- d. Placement of revetment on caving banks.
- e. Improving navigation channels for river traffic by means of dredging and training works between Cairo and New Orleans.
- f. Completion of the Mississippi River flood-control works, previously authorized but not included in the project (including levees on the main stem between Rock Island and Cape Girardeau, and on the outlets and tributaries of the Mississippi River between Rock Island and Head of Passes, insofar as they are affected by Mississippi River backwater).

104. The Flood Control Act of 1928 has been modified 24 times, with the latest being by the Water Resources Development Act of 1976.[2] The works completed or in progress as a result of the act fall under the umbrella of the Mississippi River and Tributaries (MR&T) Project. The currently authorized project consists of four major elements:

- a. Channel improvement.
- b. Placement of levees and floodwalls.
- c. Construction of floodways.
- d. Tributary reservoir construction.

The total authorized cost of the project, including modifications, is $6.1 billion, of which $2.4 billion has been spent to date (1977). Recent (1977) annual maintenance is $50 million. The most serious flood occurring since authorization of the MR&T Project (1973) inundated more

than 12 million acres and caused damages in excess of $700 million. Without the protection provided by the MR&T Project, nearly twice the acreage would have been under water, and damages would have exceeded $13 billion. Total accumulated benefits of the MR&T Project from its inauguration in 1928 to date (1977) amount to $51.7 billion.

105. The MR&T Project also provides for supplementary off-main-stem flood-control improvements in the Lower Mississippi and Arkansas-White-Red Basins to provide local protection in the St. Francis and Little River Basins in Missouri and Arkansas; at Cairo and vicinity; along the main-stem left-bank tributaries in western Kentucky and Tennessee; in the Lower White, Arkansas, and Bayou Meto Basins and the Grand Prairie Region of Arkansas; in the Tensas Basin, Arkansas and Louisiana; in the Atchafalaya Basin, Louisiana; and in the Yazoo Basin, Mississippi.[43]

106. Channel improvement. Channel improvement in the interest of both navigation and the protection of flood-control works in the alluvial valley downstream from Cairo is an integral part of the MR&T Project. This element of the project consists of the placement of revetment on unstable banks, the construction of dikes and cutoffs, and dredging (paragraphs 135-140). The cost of the channel-improvement features through FY 76 has been approximately $920 million, with annual maintenance costs of $22 million.

107. Many types of materials have been used to stabilize streambanks in the lower valley, including willow, lumber, and asphalt mattresses. To date, the most economic and effective means of protecting banks from caving and erosion along the Mississippi main stem is a subaqueous revetment composed of an articulated concrete mattress and stone riprap paving on the upper bank.[1] Six hundred miles of operative revetment are in place on the main stem between Cairo and Baton Rouge. Dikes, constructed of timber piling and riprap, are used to regulate or contract the width of the main channel during periods of low water and to direct erosive currents away from susceptible banks. The CE has placed 4,234 miles of revetment and 115 miles of dikes (374 structures) over the whole basin. In spite of the placement of these bank-protection works, some 18 percent of the total channel miles in the basin are still

actively eroding (1979). This erosion results in an annual property loss of $26.0 million and would require $125.0 million to restore the banks to their original condition.

108. By 1942, a total of 16 cutoffs and two major chutes had been developed on the Mississippi main stem. These improvements, when made, lowered river stages 16 ft at Arkansas City, Ark., and 10 ft at Vicksburg, Miss. These cutoffs are still intact and effective; however, the channel efficiency has diminished somewhat, raising stages by 2 to 3 ft. The higher stages are due primarily to the instability introduced by the cutoff program and the persistent tendency of the river to meander. The cutoffs and chutes have reduced the river distance from Memphis to Baton Rouge by over 100 miles.

109. Placement of levees and floodwalls. There are 1,608 miles of levee and floodwalls now (1977) authorized along the Mississippi River main stem below Cape Girardeau, of which 985 are built to approved grade and section. The main-stem and tributary levee system totaling 2,196 miles (of which 1,304 have been completed) includes additional levees and structures along the right bank of Arkansas River (85.4 miles); along the right bank of Red River (59.8 miles, with 43.9 completed); and 451.2 miles in the Atchafalaya River drainage, with 189.7 completed.

110. The main-stem levee line on the right bank begins just south of Cape Girardeau, and except for gaps where tributaries join the Mississippi, extends unbroken almost to the Gulf of Mexico. The longest continuous levee line in the MR&T Project, and probably in the world, begins at high ground near Pine Bluff, Ark., and follows the right bank of the Arkansas River and the right bank of the Mississippi River to a terminus in the vicinity of Venice, La., a distance of more than 650 miles. The main-stem left bank is protected by levees alternating with high bluffs except for backwater areas.

111. Construction of floodways. When the carrying capacity of the main-stem leveed channel is exceeded during a major flood, the CE uses relief outlets through the Birds Point-New Madrid, Atchafalaya Basin, West Atchafalaya, Morganza, and Bonnet Carré Floodways along with the storage capacity of lowlands (backwater areas) at the confluences of

major tributaries with the main stem.[1] These backwater areas are usually protected from lesser floods by interior levee systems that are designed to be overtopped by the major floods.

112. The left-bank bluffs and the main stem levee on the right bank of the Mississippi River between Cairo and New Madrid, Mo., form a narrow channel through which the river must flow at high stages. To protect the city of Cairo and to reduce flood heights, the CE built a setback levee 5 miles west of the main-stem levee. The strip of land between the main-stem levee and the setback levee forms the Birds Point-New Madrid Floodway. At extremely high stages, water enters the floodway through fuseplugs at Cairo and reenters the main river above New Madrid. The floodway was operated only in 1937 and greatly reduced flood stages at and upstream from Cairo.

113. From the latitude of Red River Landing, the project flood is conveyed to the Gulf of Mexico via the Mississippi and Atchafalaya Rivers, with each carrying approximately one-half of the total flow. Of the portion remaining in the main-stem channel, roughly one-sixth is diverted to Lake Pontchartrain and the Gulf of Mexico through the Bonnet Carre Spillway, located about 25 miles upstream from New Orleans. The Bonnet Carre Spillway was operated in 1937, 1945, 1950, 1973, 1975, and 1979.

114. The portion of the project flood flow diverted from the main stem into the Atchafalaya is carried equally by the Morganza Floodway and the Old River Outflow Channel (paragraph 88). Flow into the Morganza Floodway is controlled by a gated spillway at Mississippi River mile 280. Flow through the outflow channel (confluence at mile 314) is regulated by the Old River Control Structures; this flow is passed via the Red River backwater area into the Atchafalaya River and the West Atchafalaya Floodway, which is controlled by a fuseplug levee at its head. The Morganza and West Atchafalaya Floodways follow opposite sides of the Atchafalaya River until they merge into a single broad floodway (Atchafalaya Basin Floodway) that passes the flood flow to the Gulf through two outlets, Wax Lake and the Lower Atchafalaya River. The West

Atchafalaya Floodway has not been used. The Morganza Floodway was used in 1973 for the first time.

115. Tributary reservoir construction. There are no sediment-retention structures on the Mississippi main stem; however, dams have been constructed on several of the tributaries to the Mississippi to curb upstream flooding. A listing of the reservoirs in the basin having design storage capacities greater than 75,000 acre-ft is provided in Table F9 (See also Figures F7 and F8.) Four reservoirs in the upper Yazoo Subbasin provide a total storage in excess of four million acre-ft, controlling a drainage area of 4,400 square miles (32 percent of the Yazoo Subbasin). Because of the large suspended-sediment inflow into the Lower Mississippi River Basin, the collective sediment retention capacity of the reservoirs in the basin probably has little impact on main-stem loads.

## History of Suspended-Sediment Sample Collection

116. The investigation of suspended-sediment transport in the Mississippi River began in 1838 when CPT A. Talcott made a number of observations near the mouth of the river. In the following years many observations were made at scattered points along the river, including those by Humphreys and Abbot at Carrollton, La., in 1851-1853 and at Columbus, Ky., in 1858 (Table F10).[44] For many years sampling procedures and methods of analysis varied widely, and not unexpectedly differences of opinion developed on the validity of some of the data. Following creation of the MRC in 1879, these observations were continued, however, with greater standardization of procedures than had been used up to this time. A summary of sediment investigation on the Mississippi River and its tributaries prior to 1932 are provided in Tables F10 and F11.

117. A suspended-sediment sampling program was initiated in 1949 by the U. S. Army Engineer District, New Orleans (NOD), to study the effect of bank-stabilization works on the suspended loads transported by the Mississippi River and its tributaries.[20] Following the procedures developed under a cooperative project sponsored by the Subcommittee on

Sedimentation, Federal Interagency River Basin Committee, study ranges were established within NOD with standardized sampling methods being used. Suspended-sediment sampling ranges were established in October 1949 on the Mississippi River at Baton Rouge, La. (mile 230); in October 1950 on the Atchafalaya River at Simmesport, La. (mile 6); and in September 1951 on the Red River at Alexandria, La. (mile 114). The sampling ranges were located at established discharge ranges. The Mississippi River sampling range located at Baton Rouge was moved to Red River Landing, La. (mile 299), in 1957, and then to Tarbert Landing, Miss. (mile 304), after the closure of Old River in 1963.

118. In 1966, the U. S. Army Engineer District, Vicksburg (VXD), began a potamology data collection program on the Mississippi River.[46] This program was initiated to provide a data base for studies leading to a better understanding of the basic principles controlling water and sediment transport. The 300-mile reach of the Mississippi main stem passing through VXD was divided into 25 study reaches, with data being collected in each study reach as need and capability permitted. The data collected included hydrographic surveys, bed-form profiles, discharge and horizontal velocity distributions, bed-material samples, and water-surface profiles. In addition, suspended-sediment sampling programs were initiated at the main-stem discharge ranges located at Arkansas City, Vicksburg, and Natchez in 1967, 1968, and 1972, respectively. From 1967 through April 1972, samples were collected monthly; since May 1972, samples have been collected weekly.

119. An inventory of the active and recently active suspended-sediment sample collection stations in the Lower Mississippi River Basin is provided in "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin" (Reference 47). This reference also includes historic narratives for several of the stations located on the Lower Mississippi main stem and its distributaries. The narratives contain a wide variety of pertinent information, including a description of the site where the station is located, the station chronological record, sample collection procedures, laboratory sample analysis, and data

reduction and reporting procedures. Reference 47 contains narratives for the following stations:

| | |
|---|---|
| Lower Mississippi main stem | - New Orleans (Carrollton), La. |
| | - Baton Rouge, La. |
| | - Tarbert Landing, Miss. |
| | - Coochie, La. |
| | - Natchez, Miss. |
| | - Vicksburg, Miss. |
| | - Arkansas City, Ark. |
| | - Memphis, Tenn. |

In addition narratives were prepared for the following distributary stations:

| | |
|---|---|
| Atchafalaya River | - Simmesport, La. |
| Old River Outflow Channel | - near Knox Landing, La. |

120. Suspended-sediment data discussed in this appendix were provided by NOD and VXD. No permanent long-term sediment sample collection stations have been operated by the CE in those portions of Kentucky, Missouri, and Tennessee lying in the Lower Mississippi River Basin. The U. S. Geological Survey operates no permanent sediment sample collection stations in the basin. Using available information, annual (water year) data for each known suspended-sediment sample collection station in the Lower Mississippi River Basin were tabulated. These data included discharge (acre-ft), suspended-sediment load (tons), ratio of silt to total suspended-sediment load, and maximum daily suspended-sediment load (tons) occurring during the water year. A listing of all stations having at least a five-year record is provided in Table F12. The station locations are shown on the basin map (Figure F7) and on a linear streamflow diagram (Figure F8); data for the stations are presented in Figures F9-F12 (presented in same order as listed in Table F12). In order that a year of record be accepted as valid for a station where daily suspended-sediment samples were not taken, the following criterion was used: samples must have been taken on at least 10 days during each month of the year when there was flow. The available data were then adjusted to an annual basis.

## Long-Term Trends in Suspended-Sediment Regime

121. The Lower Mississippi River Basin is not a significant source area for material that can be eventually transported as suspended sediment; however, because of the strategic location of the basin between a large portion of the interior of the North American Continent and the Gulf of Mexico, it must pass large volumes of water and sediment through its major waterways. Even in its natural state, the Mississippi River was a heavy sediment-bearing stream, and if left to the natural order of events, would probably be building a new main-stem delta in what is now the Atchafalaya Subbasin. Several events in the current and past century have altered the course of natural changes and in turn have affected the suspended-sediment regime of the Lower Mississippi River main stem:

- a. The land use in the Missouri, Upper Mississippi, and Arkansas-White-Red Basins has changed from the predominately grassland-forest setting of the early nineteenth century to the current intensive use of the land for agricultural activities.
- b. In 1831 CPT Henry M. Shreve cut off Turnbull's Bend. The abandoned bend, whose arms were known as Upper and Lower Old River, showed the customary tendency to silt up. Both the channels would eventually have become permanently filled if left to themselves, and the Red and Atchafalaya would have formed a single river running parallel to the Mississippi; however, the lower channel was dredged to maintain navigation and trade between the river systems. By 1940 the Atchafalaya was providing a river route to the sea with a three-to-one advantage in bed slope over the Mississippi main-stem channel downstream from the Old River confluence. Studies[20] showed that the Atchafalaya would eventually capture the Mississippi discharge. To prevent this change in streamflow, the Old River Control Structures were completed and became operational in 1963; these structures now prevent unregulated flow from the Mississippi into the Red-Atchafalaya System.
- c. A series of sediment-retention structures were constructed in the Missouri River Basin (1953-1967), particularly in the Kansas River drainage and on the Upper Missouri main stem; the Missouri River was channelized through mile 753, and revetment was placed to eliminate further bank failures and spur dikes were placed on the river to direct erosive currents away from cut banks and

to trap suspended sediments. (See Appendices A and B for more detailed discussions of these improvements.)

d. Several sediment-retention structures were placed on the Arkansas River main stem and tributaries (1963-1970); the main-stem bank was stabilized through mile 397. (See Appendix E.)

In addition, improved land-management practices and the placement of numerous streambank protection works and sediment-retention structures on tributary streams throughout the Mississippi River Basin have undoubtedly reduced main-stem suspended-sediment loads, although these impacts are difficult to assess quantitatively.

122. The greatest single suspended-sediment contributor to the Lower Mississippi River is the Upper Mississippi, which in turn derives much of its load from the Missouri River. Although many tributaries upstream from the Upper Mississippi-Missouri confluence contribute measurable loads to the main stem, the Missouri River input dominates the character of the suspended-sediment regime of the Upper Mississippi between St. Louis and Cairo. Prior to the placement of a series of multi-purpose dams on the Missouri main stem (1953-1963), and in the Kansas River Basin (1953-1967), the average sediment load passing St. Louis was in excess of three hundred million tons per year, 90 percent of which was directly related to Missouri River input. After 1967 the average annual load at St. Louis decreased to slightly over one hundred million tons, which is generally regarded as reflecting the Upper Mississippi's current suspended-sediment contribution to the Lower Mississippi main stem.

123. Under preproject conditions,* the Ohio River contributed 60 percent of the discharge of the Lower Mississippi immediately downstream from its confluence with the Upper Mississippi, however not a proportional amount of sediment. A suspended-sediment collection station was operated on the Ohio at Paducah, Ky. (mile 45 above the confluence), from 16 Dec 1878 through 30 Dec 1879. During this period an average of 200,020 tons of suspended sediment passed this station each day. Samples were collected from the Upper Mississippi at St. Louis from 31 Mar 1879

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* That is, prior to work in the Missouri River Basin (paragraph 121).

through 25 Jun 1879 and from 15 Jan 1881 through 5 Sep 1881; during these periods the average daily suspended-sediment loads were 1,128,760 and 956,111 tons, respectively. Although the time periods differ and the sample collection methods may be questionable, a relative comparison of the average daily load at Paducah with those at St. Louis demonstrates the dominating influence of the Upper Mississippi on the main-stem suspended-sediment load downstream from Cairo, at least prior to 1900.

124. Between Cairo and the confluence of the Lower Mississippi with the Arkansas River (mile 581) there are no major suspended-sediment contributors to the main-stem load. Minor right-bank tributaries in west Tennessee (the Obion, Hatchie, Loosahatchie, and Wolf Rivers) collectively contribute an average of 4,712,000 tons per year; the St. Francis (a left-bank contributor at mile 672) inputs 1,157,000 tons per year; and the White (a left-bank contributor at mile 599) 3,700,000 tons per year. No long-term suspended-sediment sample collection stations have been operated on the main stem between Cairo and the mouth of the Arkansas; thus, there is no specific information on the average annual or maximum daily loads passing through this reach.

125. The Arkansas River is the major main-stem suspended-sediment contributor downstream from Cairo. All of the sediment is passed into the Mississippi via the Arkansas main channel with virtually none being passed through the Arkansas Post Canal into the White River, and thus into the Mississippi main stem. The hydraulic and sediment regimes of the Arkansas have been significantly altered in recent years due to improved land-use practices, channelization, and the construction of several sediment-retention structures. Prior to the construction of these impoundments (1963-1970), the average annual suspended-sediment load passing Little Rock, Ark., was in excess of 90 million tons (based on 1941-1962 data; the load passing this station is generally regarded as reflecting the contribution of the Arkansas to the Mississippi River). After completion of the upstream dams, the average annual load at Little Rock decreased to eleven million tons. Thus, upstream improvements have reduced the sediment load at Little Rock to 12 percent of its natural value, most likely reflecting a similar decrease in the contribution of

the Arkansas to the Mississippi main stem.

126. Prior to major upstream improvements (paragraph 121) the average annual suspended-sediment inflow to the Lower Mississippi main stem upstream from Vicksburg (mile 435) totaled over four hundred million tons, a figure which did not include Ohio River inflow* or input from bank failures and tributaries between Cairo and Vicksburg (Figure F13). The sum of current known contributions above Vicksburg is 135 million tons per year (Figure F14), which still does not include the contribution of the Ohio.* Extensive bank-protection works are now in place on the main stem upstream from Vicksburg; thus, bank caving is probably no longer a major sediment source through this reach. A suspended-sediment sample collection station was established at Vicksburg in 1968 and continues to operate through the present (paragraph 127). The average annual load passing this station is 225.3 million tons. The difference in the measured load at Vicksburg and the sum of the other known inputs upstream from Vicksburg is 90.3 million tons. Thus allowing for other minor input, the current suspended-sediment contribution of the Ohio to the Lower Mississippi is probably around 80 million tons per yr. This value would represent approximately 20 percent of the pre-1953 load downstream from the Upper Mississippi-Ohio confluence. The only other comparison of the Upper Mississippi and Ohio input are pre-1900 data for St. Louis and Paducah (paragraph 123). Comparison of these data also indicates that the Ohio River supplied approximately 20 percent of load; thus, since no other estimates are available, 80 million tons per year may represent a good first estimate of the annual Ohio River Basin yield.

127. In the reach between the mouth of the Arkansas and the Old River Outflow Channel (mile 314), the Mississippi receives average annual suspended-sediment contributions from the Yazoo River at mile 437 (4,244,000 tons), the Big Black River at mile 409 (908,000 tons), and the Homochitto River at mile 322 (515,000 tons). Three sediment sample collection stations are being operated through this reach by VXD; these

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* No estimate available.

are Arkansas City (mile 566), Vicksburg (mile 435), and Natchez (mile 362).[48] Although these stations do not meet the sampling frequency criteria in paragraph 120, the data from these stations are the only current information available for this reach of the main stem. Samples were collected at these stations on a monthly basis beginning in April 1967 at Arkansas City, in January 1968 at Vicksburg, and in April 1970 at Natchez; since May 1972 samples have been taken weekly at all stations. Data for the periods of record of these stations are as follows:

| | Days of Record (Through 1979) | Annual* Discharge acre-ft | Annual* Suspended-Sediment Load tons | Ratio of Silt to Total Suspended-Sediment Load** | Maximum Daily Suspended-Sediment Load tons |
|---|---|---|---|---|---|
| Arkansas City | 340 | 467,069,695 | 169,826,985 | 0.69 | 2,519,000 |
| Vicksburg | 402 | 529,950,070 | 226,447,825 | 0.61 | 2,865,000 |
| Natchez | 334 | 555,481,090 | 211,857,315 | 0.67 | 2,045,000 |

* Average of daily records adjusted to an annual basis.
** Material smaller than 0.062 mm.

128. At the Old River diversion a portion of the main-stem suspended-sediment load is routed into the Red-Atchafalaya System; the remainder is transported southward towards the Gulf of Mexico. As this load approaches Head of Passes, the "freshwater discharge" is often retarded during low flows by saltwater intrusion in the form of a wedge; as a result of the slower stream velocities, the suspended material tends to settle out. Silting problems near the mouth of the Mississippi have been encountered annually and reached critical proportions during the early 1970's. The draft and width restrictions encountered at the passes of the river have adversely affected the navigation safety of vessels transiting the area and have had a significant effect on the amount of cargo that can be imported or exported via the Mississippi River system. The continued deposition advances the 35-ft depth contour at the mouth of the river seaward about 100 ft per yr.[49]

129. Prior to the Old River Control Structures becoming operational (1963), the outflow channel passed an estimated average annual discharge of 109.6 million acre-ft and a suspended-sediment load of 97.5 million tons per year (the difference in the values measured at the Simmesport and Alexandria suspended-sediment sample collection stations; Figure F13). These values reflected one-quarter of the Mississippi main-stem's discharge and suspended-sediment load upstream from the Outflow Channel-main stem confluence. Measurements made after closure of the structures at the CE discharge and suspended-sediment sample station located on the Outflow Channel near Knox Landing indicate that the channel still passes one-quarter of the Mississippi's discharge and suspended-sediment load. Thus, the Old River Control Structures have prevented a continued escalation of the proportional part of the main-stem's discharge and suspended-sediment load being passed into the Atchafalaya, and subsequent capture of the Mississippi by the Atchafalaya.

130. During the period 1950-1962 the suspended-sediment sample collection station at Tarbert Landing passed an average load of 299 million tons per year; for the period 1970-1978 this value decreased to 161 million tons. NOD regards the station at Tarbert Landing as monitoring the suspended-sediment load of the Mississippi main stem that is available for transport to the Gulf of Mexico; the station at Simmesport reflects the current best estimate of the suspended-sediment load that is passed into the Gulf from the Atchafalaya River. Thus, the sum of the loads at these two stations (Tarbert Landing and Simmesport) can provide a first estimate of the yield of the entire Mississippi River Basin (exclusive of the bed-load portion of the yield). Prior to 1963 this sum was 434 million tons per year, but has currently declined to 255 million tons per year (Figure F14). This reduction reflects the positive benefits of numerous upstream channel improvements made by the CE, as well as improved land-use management techniques.

# PART IV: CHARACTERIZATION OF BED-MATERIAL GRADATION

131. The present Mississippi River has evolved through a series of changes in the drainage system that were brought about by valley aggradation during and subsequent to the late glacial rise of sea level. Discharge, bed slope, and the quantity and nature of the transported materials locally control the stream regime. With the possible exception of discharge, these parameters were all greatly modified as the stream system became adjusted to the gradual rise of its base level. A delicate balance between these parameters now keeps the Mississippi in a poised condition (i.e., neither aggrading nor degrading).[50]

132. The slope of the Mississippi Valley was initially flat near the Gulf of Mexico and steep in the tributary headwaters. As valley aggradation progressed inland from the Gulf, it caused a gradual lowering of slopes within the entire Mississippi River system. The alluvium deposited during the early stages of aggradation consisted of coarse sands and gravels, derived primarily from steep-gradient, braided tributary streams. These coarse deposits were continually reworked and redistributed as local load, offering little resistance to scouring or channel migration.[51]

133. The historic main stem, which was left with a flatter gradient as the valley slope gradually decreased, was unable to carry the introduced coarser part of its load as far as the Gulf of Mexico. This condition, combined with the widening of tributary valleys at their confluences with the alluvial valley, caused the development of fans that blocked tributaries and contributed to the process of tributary valley aggradation. The consequent loss in carrying power of the major tributaries resulted in a gradual decrease in the particle size and volume of bed material contributed to the Mississippi River. The dominant introduced material eventually became sands, silts, and clays, with the main-stem discharge becoming concentrated into a single channel.[51]

## Cultural Influences on Bed-Material Gradation

134. The major cultural influences on the bed-material gradation

of the streams in the Lower Mississippi River Basin are channel improvements (paragraphs 96-115) and dredging. Reservoir construction and agricultural practices currently affect the gradation of bed material to a minor degree. Reservoirs with design storage capacities in excess of 75,000 acre-ft have been built in St. Francis and Yazoo Subbasins (Table F9); however, these impoundments have probably had only a negligible effect on the bed material of the Lower Mississippi River. The influence of agriculture has been lessened since the advent of the soil conservation measures of the 1930's.

135. Dredging is necessary to maintain navigation in the Lower Mississippi River where the project depth is often jeopardized by shoaling due either to natural or man-made causes. This dredging is the responsibility of three CE districts, Memphis (MD), VXD, and NOD. Tables F13-F15 provide information on estimated cubic yardage of material removed by maintenance dredging from the Atchafalaya River Subbasin, Bonnet Carré Floodway, and the Lower Mississippi River. The period of record for these dredging statistics is fiscal years 1970 through 1978, with the exception of the Lower Mississippi River, which reflects calendar years 1933 through 1978. The material removed from the main stem of the Mississippi River represents the bulk of maintenance dredging in the basin.

136. Dredging expenditures have risen sharply in the past few years, with these increases due mainly to increases in fuel and labor costs. In NOD the 1978 maintenance dredging costs for the Lower Mississippi River ranged from \$0.323 to \$20.286/yd$^3$, depending on the location and the amount of material dredged at a site. The higher unit costs were incurred in those areas where small quantities were removed. The average unit cost (1978) for maintenance dredging performed by NOD was \$0.463/yd$^3$ for contract dredges and \$0.288/yd$^3$ for government dredges. Unit costs for Mississippi River dredging in VXD and MD are comparable with those of NOD.

137. The bulk of the maintenance dredging on the Lower Mississippi

is through channel crossings* and in the South and Southwest Passes. There are approximately 200 crossings between Cairo and Baton Rouge. Downstream from Baton Rouge there are fewer crossings, but the project channel dimensions are considerably greater. Many of the channel crossings require repetitive dredging (two or three times per season) to maintain the required navigation depths. MD indicates that it must usually dredge an average of 15 to 18 different crossings for a total of approximately 25 on-site operations each season, indicating that a number of crossings must be dredged more than once. Construction dredging and dikes have helped to alleviate some of the required maintenance dredging at a number of the MD crossings, such as New Madrid (mile 888). Prior to construction of the dikes at New Madrid (1977), MD found it necessary to dredge this crossing several times a season.

138. VXD also has a number of channel crossings that require repetitive dredging each season to maintain project navigation depths. Like MD, VXD has found dikes to be helpful in facilitating the passage of bed material so that navigation will not be jeopardized. The farthest downstream dike (constructed in 1979) in VXD is at Jackson Point (mile 331).

139. NOD maintenance dredging efforts on the Lower Mississippi River upstream from Baton Rouge are usually restricted to a few shallow crossings. Downstream from Baton Rouge where there is a 40-ft project channel, there are a number of deepwater crossings that must be dredged at least once and sometimes two or three times each season. There are no dikes in the reach of the mainstem under the jurisdiction of NOD. Maintenance dredging is also required on the Lower Mississippi River in South, Southwest, Baptiste Collette Bayou, and Tiger Passes; the latter two are less significant than South and Southwest Passes in terms of their maintenance dredging requirements.

140. NOD reported considerable shoaling in the three Atchafalaya Floodways prior to the development of an enlarged central channel.[49,53]

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* Relatively short and shallow reaches of a stream between bends where the thalweg shifts from one streambank to the other.

This shoaling had become a serious threat to the flood-carrying capacity of the floodways; however, the problem has, to a large extent, been alleviated by both construction and maintenance dredging. Dredging on the Atchafalaya main stem and its Gulf outlets now account for most of the maintenance dredging in Atchafalaya River Subbasin.

## History of Bed-Material Sample Collection

141. Samples of bed material taken from the Lower Mississippi River were collected as early as 1879, and were among the few reported in 1930 in WES Paper H.[44] The locations sampled were "Bullerton," Ark. (Osceola, Ark.), Fulton, Tenn., and Lake Providence, La. The results of the pre-1900 sampling are summarized in Table F16. During the early years of the twentieth century, there was little attempt made to characterize the bed-material gradation of the streams in the Lower Mississippi Basin. The U. S. Army Engineer Waterways Experiment Station (WES) conducted a sediment study in the Atchafalaya Subbasin during the summer of 1933. The resulting report[54] contains information on the preproject conditions of the bed material in this subbasin.

142. During August and September 1932 and May 1934, the Mississippi River Commission (MRC) collected 615 bed-material samples from the Lower Mississippi River between Cairo and the Gulf of Mexico following the Southwest Pass below the Head of Passes. The results of this effort were used to construct a plot of the bed-material gradation through this reach (Figure F15). As part of the current study "Cumulative Percent Finer Than" values were determined from Figure F15 at indicated gradation breakpoints for several locations on the Lower Mississippi between Cairo and the Head of Passes. These values were plotted on standard semilogarithmic grain-size distribution paper for each location (sample form shown in Figure F16); from each plot the percentage of the gravel/sand/silt fraction present and the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes were determined. The results are summarized in Table F17. Note that the percentages shown in Table F17 of the gravel/sand/silt fractions are in terms of the Unified Soil Classification System (which is used

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throughout this study unless otherwise noted). Table F17 indicates that the bed material in the Lower Mississippi River in 1932-1934 immediately downstream from Cairo was 20 percent gravel, 72 percent sand, and 8 percent silt. Further downstream a shift towards the smaller grain-sized fractions is evident; at the Head of Passes fine sand represented 64 percent of the total fraction with 35 percent of the remaining material being silt. The $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes also decreased downstream with the range between the $D_{84}$ and $D_{16}$ sizes becoming smaller, suggesting that the bed material was becoming more uniformly graded.

143. All records from active and inactive bed-material sample collection stations in the Lower Mississippi River Basin were examined to see which stations met either of the following criteria:

- a. A 10-year continuous record during which five or more samples were taken on at least 30 days during the period.
- b. At least two years of continuous record averaging at least five days per year on which five or more samples were taken.

The locations of those stations meeting one or both of these criterion are listed in Table F18 and their locations are shown in Figures F7 and F8. The data for the CE stations operated by NOD on the Atchafalaya River at Simmesport, La., on the Old River Outflow Channel near Knox Landing, La., and on the Mississippi River at Tarbert Landing, Miss., were used to construct the bed-material gradation envelopes presented in Figures F16-F18. These envelopes were drawn by constructing pairs of curves, one connecting the highest and the other connecting the lowest "percent finer by weight" values for selected sieve sizes from 0.062 mm to 64 mm for all samples taken at a given station. Extreme points occurring on days when fewer than five samples were taken were deleted from consideration, and the next higher (or lower) value was used. Only the data collected since 1971 were available (from a computer-retrievable data base) to construct Figures F16-F18. Envelopes for the bed-material sample collection stations operated by VXD on the Mississippi River at Natchez, Vicksburg, and Arkansas City could not be constructed because the data were not available on a sample basis; however, the annual data summaries for these stations were used to assess

long-term bed-material gradation trends occurring through the VXD reach (paragraph 152).

144. MD Survey Branch personnel have collected bed-material samples from the Mississippi River on an irregular basis at different locations since 1969. These samples were analyzed for grain-size distribution and the results are provided in Table F19. This tabulation provides the complete set of $D_{65}$ and $D_{50}$ sizes for all bed-material samples collected through 1978. The devices used to collect bed-material samples in MD are nonstandard items that were designed and fabricated locally. Prior to 1973, samples were taken with a weighted one-gallon bucket suspended from a rope. From 1973 to the present MD has used a short section of 4-in. steel pipe sealed on one end and equipped with a tilting mechanism and digging teeth on the other end; the sampler is suspended from a rope and dragged along the bottom. Both the bucket and pipe devices have distinct disadvantages when compared with the standard bed-material samplers (e.g. US BM-54) because it is impossible to close the MD samplers prior to or after the collection of a bottom sample. Thus, the flow of fines into or out of the sampler is difficult to control.

145. From 1966 through 1972 periodic bed samples were taken in 25 special potamology study reaches located throughout VXD's jurisdiction of the main stem (paragraph 118). During each sampling operation, four to twelve bed-material samples were taken depending on the width of the cross section.[48] Since 1972 samples at these ranges have been taken only at the centers of flow. $D_{84}$, $D_{50}$, and $D_{16}$ values determined from representative size distributions (paragraph 152) for each of the 25 study reaches for 1932/1934 (Reference 55) and 1966-1974 are presented in Table F20.

146. In 1966 VXD collected all bed-material samples with a drag bucket. Beginning in 1967 the district began using the US BM-54 sampler on the 25 potamology ranges with the exception of the left portion of the Vicksburg discharge range. At the Vicksburg discharge range the river channel is adjacent to a limestone bluff that extends into the bed of the river. To avoid damaging the US BM-54 sampler, VXD continues to

use the drag bucket for collection of bed-material samples on the limestone bed. During 1967, VXD took 77 companion samples using the drag bucket and the US BM-54 to determine if there was any difference in particle-size diameters of the samples collected. The $D_{84}$, $D_{50}$, and $D_{16}$ sizes for corresponding samples were compared as follows:

| | Average Size, mm | | |
|---|---|---|---|
| | $D_{84}$ | $D_{50}$ | $D_{16}$ |
| Drag bucket | 1.213 | 0.422 | 0.281 |
| BM-54 | 1.138 | 0.422 | 0.265 |
| Percent difference | 6.6 | 0.0 | 6.0 |

In almost all sample pairs, the compared sizes were very close; however, the BM-54 apparently retained slightly more of the finer material while the drag bucket gathered more of the larger material.[48]

147. In addition to the bed-material sample collection stations noted in paragraph 143, NOD operates stations in the Lower Mississippi River Basin on the Mississippi River at Coochie, La., on the Atchafalaya River at Morgan City, La., and on the Wax Lake Outlet at Calumet, La., although none of these stations meet either of the criterion in paragraph 143. NOD collected bed-material samples for the entire reach of Lower Mississippi under its jurisdiction during 1975 and for the Atchafalaya River,* 1975-1977 (Tables F21 and F22, respectively). Most bed-material samples in NOD are collected with a drag bucket, but occasionally district personnel use the US BM-54 sampler to collect samples when additional analyses for pesticides are required.

## Long-Term Trends in Bed-Material Gradation

148. No long-term bed-material sample collection stations have been operated on the Upper Mississippi or Ohio Rivers immediately upstream from their confluence which forms the Lower Mississippi River.

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* Mileage on the Atchafalaya River (established by the CE in 1963) begins at the confluence of the Old, Red, and Atchafalaya Rivers, thus the reason for the arrangement of river mileage on Table F22.

No stations have been operated downstream from Cairo, thus specific information regarding the bed-material gradation in the vicinity of the confluence is not available. Commerical dredging companies currently operating in the Upper Mississippi above Cairo indicate that the bed-material gradation is equally divided between coarse and fine sands, and that this gradation has not changed significantly over the past 50 years. (Dredging companies through this reach do not use the medium sand classification.) Dredge operators working in the Ohio River downstream from mile 800 indicate that more than 90 percent of the mined material is sand. (The majority of this sand is classified "coarse" or concrete sand.) Most companies working through this reach do not consider gravel mining economically feasible. Opinions differ among dredge operators as to changes in the bed-material gradation over the past years in the Lower Ohio River; some say no changes have taken place, while others think the limited gravel supply has declined.

149. Based on the information furnished by the commercial dredgers, the current bed-material gradation of the Lower Mississippi immediately downstream from Cairo can best be described in terms of the coarse to fine sand input from the Upper Mississippi and the coarse sand input from the Ohio. Bed-material samples collected in 1932/1934 by the MRC (paragraph 142) indicated that the gravel/sand/silt fractions below the confluence were 20, 72, and 8 percent, respectively, thus supporting the theory advanced by the Ohio River dredgers that gravel once was present in the bed material near the confluence, but has since declined to quantities that are not economically recoverable.

150. Bed-material sampling was conducted by MD in the reach of the Lower Mississippi under its jurisdiction (Cairo downstream to mile 620) from June 1969 through February 1978 (paragraph 144 and Table F19). The $D_{50}$ grain sizes for each sample were categorized into approximately 100-mile reaches; the grain sizes for each reach were then ranked to obtain a median $D_{50}$ value that would be "typical" of the reach. The results are as follows:

| Reach | Number of Samples | Median $D_{50}$ Grain Size (mm) |
|---|---|---|
| Mile 900 - Cairo | 161 | 0.52 |
| Mile 800 - Mile 900 | 257 | 0.50 |
| Mile 700 - Mile 800 | 89 | 0.49 |
| Mile 620 - Mile 700 | 128 | 0.41 |

Comparison of these $D_{50}$ values indicates a decrease in grain size from Cairo downstream to mile 620.

151. At mile 581 the Lower Mississippi receives the bed material of the Arkansas River. No long-term bed-material gradation data are available for the Lower Arkansas; however, commercial dredgers report that the bed-material from Pine Bluff (Arkansas River mile 75.0) to the mouth is fine sand.

152. The most intensive bed-material sampling program on the Lower Mississippi has been conducted in the reach passing through VXD.[48] Between 1966 and 1974 nearly 9000 samples were collected from mile 320 to mile 616 (paragraph 145 and Table F20). Of the 25 potamology study reaches established through VXD (paragraph 118), three pairs of reaches (which include the Arkansas City, Vicksburg, and Natchez discharge ranges, respectively) were selected to assess changes in the bed-material gradation occurring through the VXD reach. The available data for each pair of reaches were used to prepare representative grain-size distribution curves. The procedure for construction of a representative distribution curve is to first determine the percent of the sample weight retained on each sieve for all samples taken in each pair of reaches, sum the values for each sieve size, and then divide each sum by the number of samples. Using the resulting average for each sieve size, representative distributions were then constructed for each pair of reaches by plotting the sieve averages on standard semilogarithmic grain-size distribution paper. Values for the gravel/sand/silt fractions present in the bed material passing through the reaches were then determined from the distribution curves; in addition selected grain sizes ($D_{84}$, $D_{50}$, $D_{16}$) were read from the curves. The three pairs of reaches

were designated as Arkansas City, Vicksburg, and Natchez, respectively, and the data derived from the representative grain-size distribution curves are presented in Table F23.*

153. Below mile 320 and the Head of Passes (mile 0), NOD has collected bed-material samples at Coochie (mile 317), Tarbert Landing (mile 306), and in 1975 at 162 locations distributed along the main stem (paragraph 147). Representative grain-size distribution curves were prepared for the Coochie and Tarbert Landing stations; in addition, the 1975 data were categorized into three 100-mile reaches for which distribution curves were constructed. The resulting gravel/sand/silt fraction percentages and $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes were entered into Table F23 with the data for Arkansas City, Vicksburg, and Natchez.

154. Although the periods of record and sampling frequencies vary for the stations and reaches listed in Table F23, some generalizations are possible. At Vicksburg, the bed-material fractions are predominantly medium and fine sand; farther downstream the percentage of the medium fraction steadily decreases as the fine sand fraction increases. In the mile 200 to mile 300 reach, the fine sand represents 86 percent of the total fraction; from this reach downstream the fine sand fraction decreases and the silt fraction increases until in the 100 mile reach above the Head of Passes, the bed material is two-thirds silt and one-third fine sand. From Vicksburg downstream the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes steadily decrease with the range between the $D_{84}$ and $D_{16}$ values also decreasing. This information suggests that in addition to becoming finer the bed material becomes more uniformly graded as it moves downstream.

155. At Lower Mississippi River mile 314, a quarter of the main stem's discharge and suspended-sediment load are passed by regulated flow to the Red-Atchafalaya system via the Old River Outflow Channel

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* Additional samples have been taken at the Natchez, Vicksburg, and Arkansas City discharge ranges (1975-1979). Representative grain-size distribution curves prepared from preliminary data for these ranges produced identical gravel/sand/silt fractions and selected grain-sizes as compared with the information presented in Table F23.

(paragraph 129). The effect on the bed-material gradation of this diversion can be examined by comparing the records of the stations at Natchez (upstream from the diversion at mile 362), Tarbert Landing (downstream at mile 306), and Near Knox Landing (downstream at mile 5.5 on the Old River Outflow Channel).

| | Number of Samples | Fraction, % | | Selected Grain Sizes, mm | | |
|---|---|---|---|---|---|---|
| | | Medium Sand | Fine Sand | $D_{84}$ | $D_{50}$ | $D_{16}$ |
| Natchez | 1219 | 32 | 63 | 0.55 | 0.36 | 0.22 |
| Tarbert Landing | 283 | 20 | 76 | 0.48 | 0.28 | 0.17 |
| Near Knox Landing | 106 | 30 | 67 | 0.66 | 0.37 | 0.28 |

Comparison of the Natchez and Tarbert Landing data demonstrates the natural tendency towards finer bed-material being present at the downstream station; however, comparison of Natchez with Near Knox Landing data shows that the material has not become finer. Prior studies (paragraphs 87 and 140) indicate that, in addition to providing a bed slope advantage over the Mississippi main stem channel below the Old River Diversion, the Atchafalaya is enlarging its central channel, while the Mississippi is aggrading below the diversion. Therefore, the Old River Outflow Channel and the Atchafalaya are most likely removing fines from their bed material, while the Mississippi, subject to a diminished channel cross section and lesser bed slope, is accumulating fine material in its bed. Because of these conditions, the data presented for the three stations above are probably consistent with existing channel cross sections and bed slopes; however, the effect of the Old River diversion on the bed-material gradation of the Mississippi main stem cannot be evaluated with available information.

156. The median $D_{50}$ grain-size data collected by MD (paragraph 150) and the data in Table F23 collectively represent current knowledge of the gradation of bed material moving through the Lower Mississippi River. The current and past suspended-sediment regimes of the

Lower Mississippi were presented as numerical flow diagrams (Figures F13 and F14). The information available to describe the bed-material gradation of the river and the influence of its tributaries on the gradation is quite limited as compared with available suspended-sediment data; however, the utility of a similar diagram is obvious for quickly developing a conceptual understanding of bed-material movement through the Lower Mississippi River. Thus such a diagram was constructed (Figure F19), even though lacking in numerical data for tributary contributions and having narrative information for only a few of the major tributaries.

157. Long-term trends in the bed-material gradation of the Lower Mississippi River downstream from the mouth of the Arkansas can be evaluated by comparing the 1932/1934 data developed from samples collected by MRC (Table F17) with post-1965 data provided by VXD and NOD (Table F23). These data are compared in Table F24 for the gravel/total sand/silt fractions and the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes. Examination of this table indicates that the component fractions have remained relatively constant from Arkansas City downstream to Tarbert Landing; however, from Donaldsonville, La., to the Head of Passes there has been a pronounced shift from the sand to silt fraction. In 1932/1934, 92 percent of the bed material near the Head of Passes was sand, whereas currently the material is one-third sand and two-thirds silt. The range between the $D_{84}$ and $D_{16}$ grain sizes has decreased for the stations from Arkansas City downstream to Tarbert Landing indicating that the bed-material has tended to become more uniformly graded through this reach; the $D_{50}$ grain size has remained relatively constant. From Donaldsonville downstream the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes have all decreased between 1932/1934 and the present, further supporting the conclusion that the bed material through this reach is becoming finer.

158. The bed material of the Upper Atchafalaya River is formed from the fine sand and silt input of the Red and from the medium and fine sands of the Old River Outflow Channel (Table F25, Figure F19). Representative grain-size distributions (paragraph 152) were prepared for the NOD bed-material sampling stations on the Atchafalaya at

Simmesport and Morgan City, and at Calumet on the Wax Lake Outlet Channel (Table F25). In addition, grain-size distributions were prepared for the mile 0-mile 50, mile 50-mile 100, and mile 100-mile 140 reaches of the Atchafalaya using data resulting from samples collected by NOD in 1975-1977 (Table F22). Records from the bed-material sampling station at Simmesport (mile 8.2) indicate that the load is 29 percent medium sand and 70 percent fine sand; however, no silt is present. This fraction has apparently become part of the suspended-sediment load. Note in Table F25 that the silt fraction represented 36 percent of the total fraction at the Red River station located 23 miles upstream from Simmesport. Table F25 indicates that downstream from Simmesport the bed material of the Atchafalaya becomes finer with 68 percent of the material at Morgan City and 90 percent of the material at Calumet being silt. The range between the $D_{84}$ and $D_{16}$ grain sizes becomes smaller downstream (Table F25), indicating that the bed material also becomes more uniformly graded as it becomes finer.

## PART V: SUMMARY

159. The Lower Mississippi River Basin is not a significant source area for material that can be eventually transported as suspended sediment; however, because of the strategic location of the basin between a large portion of the interior of the North American Continent and the Gulf of Mexico, it must pass large volumes of water and sediment through its major waterways. Even in its natural state, the Mississippi River was a heavy sediment-bearing stream, and if left to the natural order of events, would probably be building a new main-stem delta in what is now the Atchafalaya Subbasin.

160. The greatest single suspended-sediment contributor to the Lower Mississippi River is the Upper Mississippi, which in turn derives much of its load from the Missouri River. Although many tributaries upstream from the Upper Mississippi-Missouri confluence contribute measurable loads to the main stem, the Missouri River input dominates the character of the suspended-sediment regime of the Upper Mississippi between St. Louis and Cairo. Prior to the placement of a series of multi-purpose dams on the Missouri main stem (1953-1963), and in the Kansas River Basin (1953-1967), the average sediment load passing St. Louis was in excess of three hundred million tons per year, 90 percent of which was directly related to Missouri River input. After 1967 the average annual load at St. Louis decreased to slightly over one hundred million tons, a value which reflects the Upper Mississippi's current suspended-sediment contribution to the Lower Mississippi main stem.

161. The Arkansas River is the major main-stem suspended-sediment contributor downstream from Cairo. The hydraulic and sediment regimes of the Arkansas have been significantly altered in recent years due to improved land-use practices, channelization, and the construction of several sediment-retention structures. Prior to the construction of these impoundments (1963-1970), the average annual load passing Little Rock was in excess of 90 million tons (based on 1941-1962 data; the load passing Little Rock is generally regarded as reflecting the contribution

of the Arkansas to the Mississippi River). After 1970, the average annual suspended-sediment load at Little Rock decreased to eleven million tons. Thus, upstream improvements have reduced the sediment load at Little Rock to 12 percent of its natural value, most likely reflecting a similar decrease in the contribution of the Arkansas to the Mississippi main stem.

162. Prior to major upstream improvements (paragraph 121) the average annual suspended-sediment inflow to the Lower Mississippi main stem upstream from Vicksburg (mile 435) totaled over four hundred million tons, a figure which did not include Ohio River inflow or input resulting from bank failures and tributaries between Cairo and Vicksburg. The sum of current known contributions upstream from Vicksburg is 135 million tons per year (Figure F14), which still does not include the contribution of the Ohio. Extensive bank protection works are now in-place on the main stem above Vicksburg, thus bank caving is probably no longer a major sediment source through this reach. The average annual suspended-sediment load now passing Vicksburg (1970-1979) is 225.3 million tons. The difference in the measured load at Vicksburg and the sum of the other known inputs upstream from Vicksburg is 90.3 million tons. Thus allowing for other minor input, the current suspended-sediment contribution of the Ohio to the Lower Mississippi is probably in the neighborhood of 80 million tons per year. This value would represent approximately 20 percent of the pre-1953 load downstream from the Upper Mississippi-Ohio confluence. The only other comparison that can be made of the Upper Mississippi and Ohio River input is with the pre-1900 data for St. Louis and Paducah (paragraph 123). These data also indicate that the Ohio River supplied approximately 20 percent of load; thus, since no other estimates of the suspended-sediment load are available, 80 million tons per year probably represents a good first estimate of the annual Ohio River Basin yield.

163. At the Old River diversion a portion of the Mississippi River suspended-sediment load is routed into the Red-Atchafalaya system; with the remainder being transported southward towards the Gulf of Mexico. Prior to the Old River Control Structures becoming operational (1963),

the Outflow Channel passed an estimated average annual discharge of 109.6 million acre-ft and an average annual suspended-sediment load of 97.5 million tons (the difference in the values measured at the Simmesport and Alexandria discharge and suspended-sediment sample collection stations; Figure F13). These values reflected one-quarter of the Mississippi main stem's discharge and suspended-sediment load upstream from the Outflow Channel-main stem confluence. Measurements made after closure of the structures at the CE discharge and suspended-sediment sample station located on the Outflow Channel near Knox Landing indicate that the channel still passes one-quarter of the Mississippi's discharge and suspended-sediment load. Thus, the Old River Control Structures have prevented a continued escalation of the proportional part of the main stem's discharge and suspended-sediment load being passed into the Atchafalaya, and subsequent capture of the Mississippi by the Atchafalaya.

164. NOD regards the suspended-sediment load passing Tarbert Landing as reflecting the load of the Mississippi main stem that is available for transport to the Gulf of Mexico; the load passing Simmesport reflects the load of the Atchafalaya River moving towards the Gulf; thus, the sum of the loads at these two stations provides a first estimate of the yield of the entire Mississippi River Basin (exclusive of the bedload portion of the yield). Prior to 1963 this sum was 434 million tons per year, but has currently declined to 255 million tons per year (Figure F14). This reduction reflects the positive benefits of numerous upstream channel improvements made by the CE, as well as improved land-use management techniques.

165. Based on the information furnished by commercial dredgers, the current bed-material gradation of the Lower Mississippi immediately downstream from Cairo can best be described in terms of the coarse to fine sand input from the Upper Mississippi and the coarse sand input from the Ohio (paragraph 148). Bed-material samples collected in 1932/1934 by the MRC (paragraph 142) indicate that the gravel/sand/silt fractions below the confluence were 20, 72, and 8 percent, respectively, thus supporting the theory advanced by the Ohio River dredgers that

gravel once was present in the bed material near the confluence, but has since declined to quantities that are not economically recoverable.

166. Bed-material sampling was conducted by MD in the reach of the Lower Mississippi under its jurisdiction (Cairo downstream to mile 620) from June 1969 through February 1978 (paragraph 144 and Table F19). The $D_{50}$ grain sizes resulting from samples collected by MD were categorized into approximately 100-mile reaches; the grain sizes for each reach were then ranked to obtain a median $D_{50}$ value that would be "typical" of the reach. Comparison of the median $D_{50}$ values indicates a decrease in grain size from the mile 900 to Cairo reach (0.52 mm) through the mile 620 to mile 700 reach (0.41 mm) (paragraph 150).

167. At mile 581 the Lower Mississippi receives the bed material of the Arkansas River. No long-term bed-material gradation data are available for the Lower Arkansas; however, commercial dredgers report that the bed material from Pine Bluff (Arkansas River mile 75.0) to the mouth is fine sand.

168. The most intensive bed-material sampling program on the Lower Mississippi has been conducted in the reach passing through VXD.[48] Between 1966 and 1974 nearly 9000 samples were collected from mile 320 to mile 616 (paragraph 145 and Table F20). Of the 25 potamology study reaches established through VXD, three pairs of reaches (which include the Arkansas City, Vicksburg, and Natchez discharge ranges, respectively) were selected to assess changes in the bed-material gradation occurring through the VXD reach. The available data were used to prepare representative grain-size distribution curves. Values for the gravel/sand/silt fractions present in the bed material passing Arkansas City, Vicksburg, and Natchez were then determined from the distribution curves; in addition selected grain sizes ($D_{84}$, $D_{50}$, $D_{16}$) were read from the curves. These data are presented in Table F23.

169. Below mile 320 and the Head of Passes (mile 0), NOD has collected bed-material samples at Coochie (mile 317), Tarbert Landing (mile 306), and in 1975 at 162 locations distributed along the main stem (paragraph 147). Representative grain-size distribution curves were prepared for the Coochie and Tarbert Landing stations; in addition, the

1975 data were categorized into three 100-mile reaches for which distribution curves were constructed. The resulting gravel/sand/silt fraction percentages and $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes were entered into Table F23 with the data for Arkansas City, Vicksburg, and Natchez.

170. Although the periods of record and sampling frequencies vary for the stations and reaches listed in Table F23, some generalizations are possible. At Vicksburg, the bed-material fractions are predominantly medium and fine sand; farther downstream the percentage of the medium fraction steadily decreases as the fine sand fraction increases. In the mile 200 to mile 300 reach, the fine sand represents 86 percent of the total fraction; from this reach downstream the fine sand fraction decreases and the silt fraction increases until in the 100-mile reach above the Head of Passes, the bed material is two-thirds silt and one-third fine sand. From Vicksburg downstream the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes steadily decrease, with the range between the $D_{84}$ and $D_{16}$ values also decreasing. This information suggests that in addition to becoming finer the bed material becomes more uniformly graded as it moves downstream.

171. At Lower Mississippi River mile 314, a quarter of the main stem's discharge and suspended-sediment load are passed by regulated flow to the Red-Atchafalaya system via the Old River Outflow Channel (paragraph 129). The effect on the bed-material gradation of this diversion can be examined by comparing the records of the stations at Natchez (upstream from the diversion at mile 362), Tarbert Landing (downstream at mile 306), and Near Knox Landing (downstream at mile 5.5 on the Old River Outflow Channel). Comparison of the Natchez and Tarbert Landing data demonstrates the natural tendency towards finer bed-material being present at the downstream station; however, comparison of Natchez with Near Knox Landing data shows that the material has not become finer. Prior studies (paragraphs 87 and 140) indicate that in addition to providing a bed slope advantage over the Mississippi main stem channel below the Old River Diversion, the Atchafalaya is enlarging its central channel, while the Mississippi is aggrading below the diversion. Therefore, the Old River Outflow Channel and the Atchafalaya

are most likely removing fines from their bed material, while the Mississippi, subject to a diminished channel cross section and lesser bed slope, is accumulating fine material in its bed. Because of these conditions, the bed-material data available for the three stations noted above are probably consistent with existing channel cross sections and bed slopes; however, the effect of the Old River diversion on the bed-material gradation of the Mississippi main stem cannot be evaluated with available information.

172. The median $D_{50}$ grain-size data collected by MD (paragraph 150) and the information in Table F23 collectively represent current knowledge of the gradation of bed material moving through the Lower Mississippi River. The current and past suspended-sediment regimes of the Lower Mississippi were presented as numerical flow diagrams (Figures F13 and F14). The information available to describe the bed-material gradation of the river and the influence of its tributaries on the gradation is quite limited as compared with available suspended-sediment data; however, the utility of a similar diagram is obvious for quickly developing a conceptual understanding of bed-material movement through the Lower Mississippi River. Thus such a diagram was constructed (Figure F19), even though lacking in numerical data for tributary contributions and having narrative information for only a few of the major tributaries.

173. Long-term trends in the bed-material gradation of the Lower Mississippi River downstream from the mouth of the Arkansas can be evaluated by comparing the 1932/1934 data developed from samples collected by MRC (Table F17) with post-1965 data provided by VXD and NOD (Table F23). These data are compared in Table F24 for the gravel/total sand/silt fractions and the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes. Examination of this table indicates that the component fractions have remained relatively constant from Arkansas City downstream to Tarbert Landing; however, from Donaldsonville to the Head of Passes there has been a pronounced shift from the sand to silt fraction. In 1932/1934, 92 percent of the bed material near the Head of Passes was sand, whereas

currently the material is one-third sand and two-thirds silt. The range between the $D_{84}$ and $D_{16}$ grain sizes has decreased for the stations from Arkansas City downstream to Tarbert Landing, indicating that the bed material has tended to become more uniformly graded through this reach; the $D_{50}$ grain size has remained relatively constant. From Donaldsonville downstream the $D_{84}$, $D_{50}$, and $D_{16}$ grain sizes have all decreased between 1932/1934 and the present, further supporting the conclusion that the bed material through this reach is becoming finer.

174. The bed material of the Upper Atchafalaya River is formed from the fine sand and silt input of the Red and from the medium and fine sands of the Old River Outflow Channel (Table F25, Figure F19). Representative grain-size distributions (paragraph 152) were prepared for the NOD bed-material sampling stations on the Atchafalaya at Simmesport and Morgan City, and at Calumet on the Wax Lake Outlet Channel (Table F25). In addition, grain-size distributions were prepared for the mile 0 to mile 50, mile 50 to mile 100, and mile 100 to mile 140 reaches of the Atchafalaya using data resulting from samples collected by NOD in 1975-1977 (Table F22). Records from the bed-material sampling station at Simmesport (mile 8.2) indicate that the load is 29 percent medium sand and 70 percent fine sand; however, no silt is present. This fraction has apparently become part of the suspended-sediment load. Note in Table F25 that the silt fraction represented 36 percent of the total fraction at the Red River station located 23 miles upstream from Simmesport. Table F25 indicates that downstream from Simmesport the bed material of the Atchafalaya becomes finer with 68 percent of the material at Morgan City and 90 percent of the material at Calumet being silt. The range between the $D_{84}$ and $D_{16}$ grain sizes becomes smaller downstream (Table F25) indicating that the bed material also becomes more uniformly graded as it becomes finer.

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Table F1

Subbasins - Lower Mississippi River Basin

| Subbasin | Area, $mi^2$ | Elevations, ft Minimum | Maximum | Average Annual Precipitation, in. |
|---|---|---|---|---|
| [illegible] River | 1,[illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] Rivers | [illegible] | 12[illegible] | [illegible] | [illegible] |
| Mississippi River Main Stem | [illegible] | [illegible] | [illegible] | |
| [illegible] River | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | |
| [illegible] River | [illegible] | 95 | 500 | [illegible] |
| Total | [illegible] | | | |

Table F2

Water Withdrawal (WD) and Consumptive Use (CU) (in millions of gallons per day) for *Major Functions and* Subbasins (1970, 1980, 2000, 2020)*

| | 1970 | | 1980 | | 2000 | | 2020 | |
|---|---|---|---|---|---|---|---|---|
| Major functions | WD | CU | WD | CU | WD | CU | WD | CU |
| Municipal | 246.9 | 91.8 | 332.8 | 122.3 | 521.5 | 193.9 | 768.9 | 286.9 |
| Industrial** | 382.5 | 59.2 | 633.8 | 96.0 | 1535.7 | 229.7 | 3,554.3 | 527.4 |
| Thermoelectric power | 1191.3 | 18.4 | 2277.3 | 38.2 | 4818.5 | 103.5 | 6,020.5 | 150.4 |
| Rural domestic | 65.1 | 65.1 | 65.0 | 65.0 | 53.2 | 53.2 | 40.7 | 40.7 |
| Total | 1885.8 | 234.5 | 3308.9 | 321.5 | 6928.9 | 580.3 | 10,384.4 | 1005.4 |
| Subbasins | | | | | | | | |
| Atchafalaya River | 196.0 | 27.0 | 370.0 | 42.4 | 1225.1 | 110.0 | 1,851.5 | 173.5 |
| Big Black-Homochitto Rivers | 113.2 | 24.8 | 245.2 | 36.3 | 839.3 | 74.9 | 1,358.8 | 153.9 |
| Mississippi Main Stem† | -- | -- | -- | -- | -- | -- | -- | -- |
| St. Francis River | 420.3 | 38.6 | 445.1 | 47.3 | 819.7 | 89.6 | 1,170.0 | 171.7 |
| Western Tennessee | 689.2 | 92.6 | 1012.3 | 127.0 | 2510.3 | 213.5 | 3,733.1 | 366.6 |
| Yazoo River | 467.1 | 51.5 | 1236.3 | 68.5 | 1534.5 | 92.1 | 2,270.6 | 139.7 |
| Total | 1885.8 | 234.5 | 3308.9 | 321.5 | 6928.9 | 580.3 | 10,384.4 | 1005.4 |

* Adapted from Reference 1.

** Includes both fresh and brackish water in the Atchafalaya River Subbasin.

† Other than for navigation, recreation, and fish and wildlife purposes, the Mississippi River Main-Stem Subbasin has very few water needs of its own.

Table F3

1977 Freight and Passenger Traffic in the Lower Mississippi River Basin and Connecting Waterways*

| Stream | Reach | Freight Traffic short tons | No. of Passengers |
|---|---|---|---|
| Atchafalaya River | Gulf of Mexico to Morgan City, La. | 3,715,862 | |
| | Morgan City to Old River Lock (121 miles) | 5,981,429 | |
| Big Pigeon and Little Pigeon Bayous | Entire project (channels connecting Atchafalaya River and Gulf Intra-coastal Waterway - Morgan City to Port Allen Route) | 98,682 | |
| Gulf Intracoastal Waterway | Rigolets to Innerhar-bor Navigation Canal | 20,615,683 | |
| | Mississippi River to Sabine River, Tex. | 63,277,175 | 143,030 |
| Gulf Intracoastal Waterway, Morgan to Port Allen Route | | 18,456,491 | |
| Innerharbor Navigation Canal | Mississippi River to Lake Pontchartrain and Mississippi River Gulf Outlet | 10,733,569 | |
| Mississippi River | Mouths of Passes to New Orleans | 266,473,450 | 305,153 (excursion) 53,013 (regular) |
| | New Orleans to Baton Rouge | 274, 065,803 | 29,557 |
| | Baton Rouge to Ohio River | 124,061,787 | 30,435 |

(Continued)

* Source: Reference 23.

Table F3 (Concluded)

| Stream | Reach | Freight Traffic short tons | No. of Passengers |
|---|---|---|---|
| Waterway from Empire, La., to Gulf of Mexico | | 212,462 | |
| Wolf River | Mouth to mile 3 | 1,174,613 | |
| Yazoo River | Mississippi River to confluence of old and new channels of Yazoo River | 1,940,184 | |
| | Confluence of old and new channels of Yazoo River to mouth of Yalobusha River (161 miles) | 525,082 | |

Table F4

Dates of Settlement for Selected Cities in the Lower Mississippi River Basin

| City | Date |
|---|---|
| Natchez, Miss. | 1716 |
| New Orleans, La. | 1718 |
| Baton Rouge, La. | 1719 |
| New Madrid, Mo. | 1783 |
| Memphis, Tenn. | 1818 |
| Helena, Ark. | 1820 |
| Vicksburg, Miss. | 1825 |
| Greenville, Miss. | 1828 |
| Morgan City, La. | 1857 |

Table F5

Population in the Lower Mississippi River Basin 1900-1970*

| Year | Population |
|---|---|
| 1900 | 1,733,486 |
| 1910 | 1,978,159 |
| 1950 | 2,604,637 |
| 1960 | 2,629,974 |
| 1970 | 2,648,625 |
| 1980 | 3,100,219 |
| 2000 | 3,979,292 |
| 2020 | 5,164,781 |

* Adapted from References 1 and 27.

Table F6

Land-Use Data - Lower Mississippi River Basin

| State | Land Use, acres: Cropland | Pasture and Range | Forest* | Other Land* | Total Land Area |
|---|---|---|---|---|---|
| | | 1860 | | | |
| Arkansas | 182,861 | 699,834 | 2,246,479 | | 3,129,174 |
| Kentucky | 178,874 | 269,546 | 347,342 | | 795,762 |
| Louisiana | 184,883 | 439,097 | 1,687,060 | | 2,311,040 |
| Mississippi | 1,981,217 | 4,213,680 | 7,080,429 | | 13,275,326 |
| Missouri | 615,941 | 1,354,561 | 1,376,263 | | 3,346,765 |
| Tennessee | 1,008,428 | 2,058,876 | 1,971,743 | | 5,039,047 |
| Total | 4,152,204 | 9,035,594 | 14,709,316 | | 27,897,114 |
| | (14.88%) | (32.39%) | (52.73%) | | |

(Continued)

* Forest and other land categories were not separately surveyed for the 1860 census (Reference 39).

(Sheet 1 of 4)

Table F6 (Continued)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1910 | | | |
| Arkansas | 770,675 | 39,050 | 453,359 | 1,866,090 | 3,129,174 |
| Kentucky | 549,052 | 11,857 | 143,266 | 91,587 | 795,762 |
| Louisiana | 415,987 | 92,442 | 231,104 | 1,571,507 | 2,311,040 |
| Mississippi | 4,991,022 | 899,607 | 3,245,912 | 4,138,785 | 13,275,326 |
| Missouri | 1,193,337 | 24,683 | 529,135 | 1,599,610 | 3,346,765 |
| Tennessee | 2,539,355 | 303,201 | 1,210,679 | 985,812 | 5,039,047 |
| Total | 10,459,428 | 1,370,840 | 5,813,455 | 10,253,391 | 27,897,114 |
| | (37.49%) | (4.91%) | (20.84%) | (36.76%) | |

(Continued)

(Sheet 2 of 4)

Table F6 (Continued)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1935 | | | |
| Arkansas | 1,266,546 | 232,668 | 514,701 | 1,115,259 | 3,129,174 |
| Kentucky | 186,218 | 262,365 | 97,276 | 249,903 | 795,762 |
| Louisiana | 300,435 | 138,662 | 161,773 | 1,710,170 | 2,311,040 |
| Mississippi | 3,845,855 | 2,072,087 | 3,282,202 | 4,075,182 | 13,275,326 |
| Missouri | 1,275,867 | 388,299 | 463,944 | 1,218,655 | 3,346,765 |
| Tennessee | 1,807,362 | 971,177 | 943,801 | 1,316,707 | 5,039,047 |
| Total | 8,682,283 | 4,065,258 | 5,463,697 | 9,685,876 | 27,897,114 |
| | (31.12%) | (14.57%) | (19.59%) | (34.72%) | |

(Continued)

(Sheet 3 of 4)

Table F6 (Concluded)

| State | Land Use, acres | | | | |
|---|---|---|---|---|---|
| | Cropland | Pasture and Range | Forest | Other Land | Total Land Area |
| | | 1967 | | | |
| Arkansas | 2,149,353 | 118,487 | 624,786 | 236,548 | 3,129,174 |
| Kentucky | 424,089 | 131,334 | 198,460 | 41,879 | 795,762 |
| Louisiana | 323,546 | 184,883 | 808,864 | 993,747 | 2,311,040 |
| Mississippi | 4,392,541 | 1,978,540 | 5,928,929 | 975,316 | 13,275,326 |
| Missouri | 1,820,925 | 240,959 | 681,074 | 603,807 | 3,346,765 |
| Tennessee | 2,395,626 | 669,408 | 1,676,955 | 297,058 | 5,039,047 |
| Total | 11,506,080 | 3,323,611 | 9,919,068 | 3,148,355 | 27,897,114 |
| | (41.24%) | (11.91%) | (35.56%) | (11.29%) | |

(Sheet 4 of 4)

Table F7

Estimated Annual Sediment Yield of Subbasins in the Lower Mississippi River Basin*

| Subbasin | Natural Area, $mi^2$ | Contributing Area, $mi^2$ | Unit Annual Sediment Yield tons/$mi^2$ | Annual Sediment Yield tons |
|---|---|---|---|---|
| Atchafalaya River | 1,886 | 345 | 157 | 54,165 |
| Big Black-Homochitto Rivers | 8,646 | 4,369 | 686 | 2,997,134 |
| Mississippi River Main Stem | 2,436 | 45 | ** | ** |
| St. Francis River | 9,250 | 1,538 | 757 | 1,164,266 |
| Western Tennessee | 10,762 | 5,784 | 1029 | 5,951,736 |
| Yazoo River | 13,838 | 4,510 | 941 | 4,243,910 |
| Lower Mississippi River Basin | 46,818 | 16,591 | 869 | 14,411,211 |

* Subbasin estimates were computed on an areal basis using unit sediment yields from Reference 1. These estimates are cumulative sums and do not reflect measures that have been taken to minimize stream sediment loads (i.e., impoundments, dikes, soil conservation practices, etc.); nor do the estimates account for sediment originating in upstream areas outside the subbasin that eventually must pass through the subbasin. Thus, the estimates provided in this table more properly reflect the potential areal yields of the subbasins rather than actual yields.

** No data available; yield is probably insignificant when compared with total basin yield due to small contributing area.

Table F8

Percentage of Subbasin Land Area Affected by Erosion*

| Subbasin | Land Area Affected by Erosion percent 1970 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Atchafalaya River | 9.3 | 9.2 | 9.1 | 8.8 |
| Big Black-Homochitto Rivers | 67.2 | 65.5 | 65.6 | 65.6 |
| Mississippi River Main Stem | 2.4 | 2.4 | 2.4 | 2.4 |
| St. Francis River | 17.9 | 17.3 | 16.5 | 16.2 |
| Western Tennessee | 56.7 | 56.5 | 56.3 | 55.9 |
| Yazoo River | 37.4 | 37.7 | 37.6 | 37.5 |

* Adapted from Reference 1.

Table F9

Dams - Lower Mississippi River Basin*

| Subbasin | Stream | Dam | River Mile | Date of Closure | Contributing Drainage Area, $mi^2$ Natural | Current** (1977) | Design Storage Capacity acre-ft | Date of Last Sediment Deposition Survey | Remaining Storage Capacity acre-ft | Average Annual Sediment Inflow acre-ft | tons | Responsible Agency† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St. Francis River | St. Francis River | Wappapello | 225.0 | 1941 | 1,310 | 1,206 | 613,200 | Mar 1964 | | 688 | | CE |
| | Wapanocca Bayou | Wapanocca | | 1964 | | | 111,000 | | | | | U. S. Dept. of Interior |
| Yazoo River | Coldwater River | Arkabutla | 54.3 | 1943 | 1,000 | 948 | 525,300 | May 1962 | | 588 | 767,900 | CE |
| | Little Tallahatchie River | Sardis | 25.7 | 1940 | 1,545 | 1,454 | 1,569,900 | May 1960 | | 999 | 1,305,700 | CE |
| | Yalobusha River | Grenada | 63.6 | 1954 | 1,320 | 1,219 | 1,337,400 | May 1965 | | 1,469 | 1,919,900 | CE |
| | Yocona River | Enid | 113.6 | 1951 | 560 | 516 | 660,000 | May 1961 | | 288 | 376,200 | CE |

* With design storage capacities $\geq$ 75,000 acre-ft.
** Current (1977) contributing drainage areas include many small catchment structures whose retention efficiencies have not been inventoried.
† CE - Corps of Engineers.

Table F10

Summary of Pre-1900 Data for Suspended-Sediment Sample Collection Stations on the Lower Mississippi River*

| Station | River Mile** | Observation Period: Dates | Observation Period: No. of Days Sampled | Discharge, acre-ft: Maximum | Discharge, acre-ft: Mean | Discharge, acre-ft: Minimum | Suspended-Sediment Load, tons/day: Maximum | Suspended-Sediment Load, tons/day: Mean | Suspended-Sediment Load, tons/day: Minimum |
|---|---|---|---|---|---|---|---|---|---|
| Columbus, Ky. | 21 | 15 Mar 1858- 15 Nov 1858 | 145 | 2,538,880 | 1,057,069 | 255,872 | 2,930,455 | 1,187,028 | 36,478 |
| | | 4 Mar 1879- 2 Jul 1879 | 79 | 1,507,460 | 745,191 | 443,965 | 5,714,207 | 1,468,113 | 238,084 |
| Fulton, Tenn. | 175 | 28 Nov 1879- 10 Oct 1880 | 178 | 2,113,149 | 1,110,309 | 305,852 | 5,116,090 | 1,325,316 | 225,547 |
| Hampton Landing, Ark. | 105 | 16 Jan 1879- 27 Jun 1879 | 105 | 1,705,810 | 1,013,112 | 396,700 | 3,723,795 | 823,418 | 137,441 |
| Helena, Ark. | 306 | 13 Dec 1878- 18 Jun 1879 | 185 | 1,626,470 | 1,024,825 | 317,360 | 2,711,837 | 992,425 | 186,019 |
| Lake Providence, La. | 542 | 18 Nov 1879- 15 Oct 1880 | 28 | 2,100,527 | 1,058,622 | 396,700 | 2,566,296 | 1,004,590 | 133,704 |
| Kings Point, Miss. | 595 | 17 Jan 1879- 30 May 1879 | 76 | 1,929,946 | 1,447,745 | 710,093 | 3,001,190 | 1,126,094 | 474,206 |
| Carrollton, La. | 960 | 17 Feb 1851- 20 Feb 1853 | 624 | 3,054,987 | 1,329,400 | 464,139 | 4,503,557 | 1,318,248 | 117,504 |
| | | 19 Dec 1879- 8 Oct 1880 | 29 | 1,794,076 | 1,020,443 | 446,375 | 2,597,443 | 995,410 | 116,554 |

* Data adapted from Reference 44.
** All river miles are below Cairo, Ill.

Table F11

Summary of 1929-31 Data for Suspended-Sediment Sample Collection Stations in the Lower Mississippi River Basin*

| Station | River Mile** | Observation Period: Dates | Observation Period: No. of Days Sampled | Discharge, acre-ft: Maximum | Discharge, acre-ft: Mean | Discharge, acre-ft: Minimum | Suspended-Sediment Load, tons/day: Maximum | Suspended-Sediment Load, tons/day: Mean | Suspended-Sediment Load, tons/day: Minimum |
|---|---|---|---|---|---|---|---|---|---|
| Atchafalaya River at Simmesport, La. | 5 | 19 Mar 1929-22 Jun 1929 | 23 | 755,714 | 652,572 | 408,601 | 521,597 | 341,280 | 201,355 |
| | | 23 Sep 1930-27 Feb 1931 | 60 | 146,779 | 73,390 | 43,637 | 596,030 | 117,936 | 13,565 |
| Atchafalaya River Morgan City, La. | -- | 10 Apr 1929-24 Jun 1929 | 17 | 725,681 | 619,050 | 477,522 | 361,066 | 179,712 | 110,506 |
| Mississippi River at Hickman, Ky. | 36* | 21 Mar 1929-10 Jun 1929 | 15 | 3,146,259 | 2,759,049 | 2,052,986 | 4,979,664 | 3,282,200 | 1,854,274 |
| Mississippi River at Helena, Ark. | 307* | 2 Sep 1930-28 Feb 1931 | 84 | 646,621 | 305,459 | 224,136 | 454,075 | 146,016 | 39,312 |
| Mississippi River at Friars Point, Miss. | 318* | 22 Mar 1929-18 Jun 1929 | 14 | 3,091,362 | 2,723,346 | 1,753,860 | 3,470,990 | 1,753,920 | 1,166,357 |
| Mississippi River at Arkansas City, Ark. | 429* | 2 Apr 1929-25 Jun 1929 | 25 | 3,485,081 | 2,798,719 | 1,834,297 | 2,628,720 | 1,674,432 | 719,798 |
| | | 2 Sep 1930-17 Jan 1931 | 81 | 432,403 | 291,575 | 220,169 | 958,738 | 213,192 | 38,534 |
| Mississippi River at Vicksburg, Miss. | 602* | 13 Mar 1929-6 Jun 1929 | 16 | 3,312,994 | 2,713,428 | 1,917,572 | 3,171,096 | 2,064,960 | 1,477,526 |
| | | 28 Aug 1930-26 Jan 1931 | 62 | 400,667 | 295,542 | 245,954 | 839,549 | 179,755 | 24,797 |

(Continued)

* Data adapted from Reference 45.

** All Mississippi River miles are below Cairo, Ill.

Table F11 (Concluded)

| Station | River Mile* | Observation Period: Dates | Observation Period: No. of Days Sampled | Discharge, acre-ft: Maximum | Discharge, acre-ft: Mean | Discharge, acre-ft: Minimum | Suspended-Sediment Load, tons/day: Maximum | Suspended-Sediment Load, tons/day: Mean | Suspended-Sediment Load, tons/day: Minimum |
|---|---|---|---|---|---|---|---|---|---|
| Mississippi River at Tarbert's Landing, Miss. | 768* | 19 Mar 1929–21 Jun 1929 | 25 | 3,104,894 | 2,753,098 | 2,082,403 | 2,365,762 | 1,473,120 | 827,021 |
| Mississippi River at Red River Landing, La. | 773* | 3 Mar 1929–22 Jun 1929 | 25 | 2,455,573 | 2,201,685 | 1,799,485 | 1,612,397 | 1,123,200 | 756,346 |
| | | 23 Sep 1930–26 Feb 1931 | 65 | 682,324 | 384,799 | 249,921 | 1,009,886 | 297,259 | 64,022 |
| Mississippi River at Carrollton, La. | 967* | 12 Mar 1929–25 Jun 1929 | 40 | 2,755,770 | 2,146,966 | 1,382,991 | 4,263,106 | 2,315,520 | 857,736 |
| | | 16 Sep 1930–27 Feb 1931 | 65 | 686,291 | 376,865 | 249,921 | 499,781 | 132,797 | 19,829 |
| Old River at Torras, La. | -- | 19 Mar 1929–22 Jun 1929 | 25 | 446,089 | 408,442 | 311,689 | 378,648 | 248,832 | 148,090 |
| | -- | 23 Sep 1930–26 Feb 1931 | 60 | 41,058 | -14,927** | -98,977** | 31,968 | -25,531** | -351,821** |
| Yazoo River at Vicksburg, Miss. | -- | 11 Jun 1929–29 Jun 1929 | 5 | 265,148 | 207,284 | 172,247 | 236,779 | 151,243 | 86,875 |
| Yazoo River at Greenwood, Miss. | 186 | 16 Sep 1930–26 Sep 1931 | 121 | 25,190 | 10,445 | 2,003 | 35,424 | 6,264 | 143 |

* All Mississippi River miles are below Cairo, Ill.

** Negative sign indicates flow from the Red River to the Mississippi River. Other discharges are from the Mississippi to the Atchafalaya River.

Table F12

Suspended-Sediment Sample Collection Stations - Lower Mississippi River Basin

| Subbasin | Stream | Station | River Mile | Period of Record* Water Yrs | Contributing Drainage Area Above Station** $mi^2$ | Responsible Agency† |
|---|---|---|---|---|---|---|
| Atchafalaya River | Atchafalaya River | Simmesport, La. | 8.2 | 1952 | 87,570 | CE |
| | Old River Outflow Channel | Near Knox Landing, La. | 5.5 miles downstream from Old River Control Structures | 1965 | 1,128,700 | CE |
| Mississippi River Main Stem | Mississippi River | Tarbert Landing, Miss. | 306.3 | 1950 | 1,128,900 | CE |
| | | Near Coochie, La. | 317.2 | 1966-1972 | 1,127,160 | CE |

* Water years of complete record inclusive. Years standing alone indicate the beginning of a period of record of a currently operating station.

** Natural flows affected by irrigation development and by storage in an undetermined number of large and small reservoirs.

† CE - Corps of Engineers.

Table F13

Maintenance Dredging in the Atchafalaya River Subbasin*

| Fiscal Year | Estimated Quantity of Material Dredged $yd^3$ |
|---|---|
| 1970 | 3,461,500 |
| 1971 | 4,597,500 |
| 1972 | 3,037,300 |
| 1973 | 4,091,100 |
| 1974 | 10,801,100 |
| 1975 | 6,027,700 |
| 1976 | 7,557,400 |
| 1976-T | 1,297,900 |
| 1977 | 9,739,200 |
| 1978 | 1,365,700 |

* File information provided by U. S. Army Engineer Division, Lower Mississippi Valley.

Table F14

Maintenance Dredging on Bonnet Carré Floodway*

| Fiscal Year | Estimated Quantity of Material Dredged $yd^3$ |
|---|---|
| 1970 | 0 |
| 1971 | 0 |
| 1972 | 0 |
| 1973 | 1,981,000 |
| 1974 | 1,397,300 |
| 1975 | 1,423,300 |
| 1976 | 0 |
| 1976-T | 0 |
| 1977 | 0 |
| 1978 | 0 |

* File information provided by U. S. Army Engineer Division, Lower Mississippi Valley.

Table F15

Maintenance Dredging on the Lower Mississippi River*

| Calendar Year | Estimated Quantity of Material Dredged, $yd^3$ Memphis District | Vicksburg District | New Orleans District |
|---|---|---|---|
| 1931 | 14,366,100 | 1,783,800 | |
| 1933 | 16,560,700 | 8,084,900 | |
| 1934 | 36,702,000 | 13,802,500 | |
| 1935 | 35,158,600 | 17,369,000 | |
| 1936 | 49,001,000 | 20,628,000 | |
| 1937 | 41,477,000 | 31,271,200 | |
| 1938 | 37,526,700 | 20,877,700 | |
| 1939 | 33,734,500 | 16,289,400 | |
| 1940 | 59,721,100 | 15,357,600 | |
| 1941 | 30,112,800 | 16,729,300 | |
| 1942 | 23,048,600 | 31,633,000 | |
| 1943 | 29,947,000 | 18,140,700 | |
| 1944 | 44,421,900 | 9,207,900 | |
| 1945 | 25,662,400 | 3,572,500 | |
| 1946 | 19,903,000 | 4,850,900 | |
| 1947 | 34,024,900 | 3,913,400 | |
| 1948 | 33,958,400 | 5,772,200 | |
| 1949 | 31,124,200 | 2,656,000 | |
| 1950 | 38,878,200 | 5,545,500 | 1,761,400 |
| 1951 | 34,701,800 | 1,223,100 | 3,002,000 |
| 1952 | 38,603,800 | 4,311,900 | 1,316,500 |
| 1953 | 54,392,100 | 3,497,700 | 1,183,500 |
| 1954 | 30,694,600 | 4,202,000 | 917,700 |
| 1955 | 32,085,700 | 6,996,600 | 1,723,100 |
| 1956 | 35,016,600 | 6,420,800 | 1,198,300 |
| 1957 | 30,909,700 | 5,092,400 | 1,463,200 |
| 1958 | 33,510,800 | 7,581,300 | 2,395,900 |
| 1959 | 40,646,300 | 3,317,500 | 1,821,800 |
| 1960 | 36,660,400 | 7,997,600 | 2,349,500 |
| 1961 | 37,499,700 | 9,626,100 | 2,550,100 |
| 1962 | 43,359,900 | 10,257,000 | 6,211,600 |
| 1963 | 42,660,500 | 11,797,100 | 9,163,600 |
| 1964 | 44,257,500 | 10,506,700 | 13,043,500 |
| 1965 | 49,540,600 | 13,302,300 | 15,925,200 |
| 1966 | 55,756,300 | 11,155,100 | 16,841,600 |
| 1967 | 46,855,900 | 10,421,200 | 15,397,800 |
| 1968 | 49,308,300 | 12,505,100 | 22,700,600 |
| 1969 | 23,975,800 | 10,760,700 | 23,203,600 |
| 1970 | 20,513,700 | 20,787,900 | 20,330,800 |

(Continued)

* Reference 52 and file information provided by the U. S. Army Engineer Division, Lower Mississippi Valley, and U. S. Army Engineer Districts, Memphis and Vicksburg.

Table F15 (Continued)

| Calendar Year | Estimated Quantity of Material Dredged, $yd^3$ Memphis District | Vicksburg District | New Orleans District |
|---|---|---|---|
| 1971 | 28,530,400 | 4,569,300 | 13,739,900 |
| 1972 | 29,479,400 | 7,028,800 | 13,005,200 |
| 1973 | 34,671,000 | 8,833,500 | 62,508,100 |
| 1974 | 41,934,100 | 11,261,700 | 45,651,300 |
| 1975 | 15,304,400 | 7,547,400 | 39,702,800 |
| 1976 | 17,940,700* | 7,750,100 | 28,678,600 |
| 1977 | 19,260,800** | 4,773,400 | 29,721,600 |
| 1978 | 28,066,000 | 3,190,000 | 21,832,100 |

* 1976-1977 low-water season, 20 May 1976 to 29 March 1977.
** 1977 low-water season, 26 May 1977 to 11 November 1977.

Table F16

Summary of Pre-1900 Bed-Material Sample Collection Stations on the Lower Mississippi River*

| Reach | River Mile** | Observation Period: Date | Observation Period: No. of Days Sampled | No. of Samples Taken | Average Percentage (by Weight) of Particles for a Given Diameter Range (in.): >0.75 | 0.25-0.75 | 0.1-0.25 | 0.01-0.1 | <0.01 |
|---|---|---|---|---|---|---|---|---|---|
| "Bullerton," Ark. (Osceola, Ark.) | 168 | 1880 | -- | -- | 2 | 4 | 3 | 60 | 31 |
| Fulton, Tenn. | 175 | 1880 | -- | -- | 2 | 6 | 4 | 70 | 18 |
| Lake Providence, La | 542-548 | 29 Jan 1879-6 Sep 1879 | 12 | -- | 0.2 | 0.4 | 2.0 | 48.2 | 49.2 |

* Source: Reference 44.
** All river miles are below Cairo, Ill.

Table F17

1932/1934 Bed-Material Fractions and Selected Grain Sizes for the Lower Mississippi River*

| | Miles Below Cairo† | Fraction, %** | | | | | Selected Grain Sizes, mm | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Gravel | Coarse Sand | Medium Sand | Fine Sand | Silt | $D_{84}$ | $D_{50}$ | $D_{16}$ |
| Cairo, Ill. | 0 | 20 | 8 | 30 | 34 | 8 | 7.0 | 0.51 | 0.16 |
| Memphis, Tenn. | 229 | 3 | 2 | 50 | 45 | 0 | 0.75 | 0.44 | 0.31 |
| Arkansas City, Ark. | 437 | 7 | 3 | 37 | 48 | 5 | 0.90 | 0.40 | 0.16 |
| Vicksburg, Miss. | 602 | 8 | 2 | 26 | 61 | 3 | 0.80 | 0.36 | 0.14 |
| Natchez, Miss. | 706 | 4 | 6 | 25 | 65 | 0 | 0.60 | 0.34 | 0.15 |
| Tarbert Landing, Miss. | 767 | 2 | 2 | 23 | 68 | 5 | 0.55 | 0.30 | 0.13 |
| Donaldsonville, La. | 896 | -- | -- | 13 | 84 | 3 | 0.40 | 0.21 | 0.12 |
| Head of Passes, La. | 1069 | -- | -- | 1 | 64 | 35 | 0.23 | 0.12 | Silt |

* Based on samples collected by the Mississippi River Commission, August-September 1932 and May 1934.
** Fractions based on Unified Soil Classification System.
† 1932 mileage.

Table F18

Selected Bed-Material Sample Collection Stations - Lower Mississippi River Basin

| Subbasin | Stream | Station | River Mile | Period of Record Water Years* | Total Number of Days Sampled | Total Number of Samples Taken | Responsible Agency† |
|---|---|---|---|---|---|---|---|
| Atchafalaya River | Atchafalaya River | Simmesport, La. | 8.2 | 1952** | 151 | 151 | CE |
| | Old River Outflow Channel | Near Knox Landing, La. | 5.5 miles downstream from Old River Control Structures | 1963** | 108 | 108 | CE |
| Mississippi River Main Stem | Mississippi River | Tarbert Landing, Miss. | 306.3 | 1950** | 261 | 261 | CE |
| | | Natchez, Miss. | 362.3 | 1971 | 343 | 2044 | CE |
| | | Vicksburg, Miss. | 435.4 | 1968 | 410 | 2263 | CE |
| | | Arkansas City, Ark. | 565.9 | 1967 | 371 | 2203 | CE |

* Years standing alone indicate the beginning of a period of record of a currently operating station.
** Only data beginning in 1971 through the present are available.
† CE - Corps of Engineers.

Table F19

Average $D_{65}$ and $D_{50}$ Grain Sizes for Bed-Material Samples Collected on the Lower Mississippi River from 1969 through 1978 by U. S. Army Engineer District, Memphis*

| River Mile | Date | Average Grain Size $D_{65}$, mm | Average Grain Size $D_{50}$, mm |
|---|---|---|---|
| 949.2 | 10 Jun 1970 | 0.63 | 0.50 |
| | 4 Dec 1970 | 0.69 | 0.51 |
| | 27 May 1971 | 0.57 | 0.46 |
| | August 1974 | 1.13 | 0.68 |
| | November 1974 | 0.92 | 0.66 |
| | 11 Nov 1975 | 1.04 | 0.57 |
| | 5 May 1976 | 0.58 | 0.45 |
| | 10 Sep 1976 | 0.54 | 0.33 |
| | 8 Jun 1977 | 0.31 | 0.28 |
| 942.7 | 14 Jun 1969 | 0.62 | 0.52 |
| | December 1969 | 0.57 | 0.44 |
| | 5 Jun 1970 | 0.96 | 0.74 |
| | 4 Dec 1970 | 0.65 | 0 53 |
| | 24 May 1979 | 0.80 | 0.64 |
| | August 1974 | 0.80 | 0.58 |
| | November 1974 | 0.61 | 0.44 |
| | 11 Nov 1975 | 0.50 | 0.42 |
| | 5 May 1976 | 0.67 | 0.51 |
| | 5 Nov 1976 | 1.08 | 0.70 |
| | 8 Jun 1977 | 0.99 | 0.54 |
| 936.2 | 28 Jun 1971 | 0.55 | 0.46 |
| | November 1974 | 4.94 | 2.40 |
| | 4 Nov 1975 | 0.94 | 0.70 |
| | 11 May 1976 | 1.17 | 0.92 |
| | 26 Oct 1976 | 0.41 | 0.36 |
| | 30 Aug 1977 | 0.40 | 0.37 |
| | 12 Dec 1977 | 0.59 | 0.47 |
| 935.0 | 25 Jun 1971 | 0.48 | 0.40 |
| | November 1974 | 0.77 | [illegible]30 |
| | 4 Nov 1975 | 9.13 | [illegible].06 |
| | 11 May 1976 | 8.75 | 5.35 |
| | 26 Oct 1976 | 13.80 | 10.08 |
| | 29 Aug 1977 | 3.88 | 1.70 |
| | 12 Dec 1977 | 0.49 | 0.38 |

(Continued)

* File information provided by U. S. Army Engineer District, Memphis.

(Sheet 1 of 7)

Table F19 (Continued)

| River Mile | Date | Average Grain Size $D_{65}$, mm | $D_{50}$, mm |
|---|---|---|---|
| 934.3B* | 25 Jun 1971 | 0.53 | 0.44 |
| | November 1974 | 6.86 | 4.31 |
| | 4 Nov 1975 | 4.33 | 2.01 |
| | 11 May 1976 | 0.45 | 0.36 |
| | 26 Oct 1976 | 13.74 | 10.46 |
| | 29 Aug 1977 | 0.59 | 0.41 |
| | 12 Dec 1977 | 0.33 | 0.38 |
| 932.4B* | 24 Jun 1971 | 0.88 | 0.61 |
| | November 1974 | 0.97 | 0.76 |
| | 10 Nov 1975 | 0.63 | 0.54 |
| | 11 May 1975 | 1.10 | 0.79 |
| | 26 Oct 1976 | 11.80 | 3.43 |
| | 1 Sep 1977 | 1.40 | 0.88 |
| | 12 Dec 1977 | 0.93 | 0.67 |
| 932.2 | 24 Jun 1971 | 1.34 | 1.09 |
| | November 1974 | 0.48 | 0.44 |
| | 7 Nov 1975 | 0.38 | 0.34 |
| | 11 May 1976 | 0.39 | 0.36 |
| | 26 Oct 1976 | 0.36 | 0.33 |
| | 31 Aug 1977 | 0.36 | 0.33 |
| | 12 Dec 1977 | 0.83 | 0.69 |
| 887.2 | 12 Aug 1977 | 0.53 | 0.43 |
| | 18 Nov 1977 | 0.79 | 0.65 |
| 886.6 | 12 Aug 1977 | 0.38 | 0.33 |
| | 18 Nov 1977 | 0.70 | 0.59 |
| 886.0 | 12 Aug 1977 | 0.61 | 0.51 |
| | 16 Nov 1977 | 0.62 | 0.45 |
| 885.6 | 15 Aug 1977 | 0.64 | 0.50 |
| | 16 Nov 1977 | 0.74 | 0.50 |
| 885.2 | 15 Aug 1977 | 0.19 | 0.10 |
| | 16 Nov 1977 | 0.39 | 0.30 |
| 884.8 | 15 Aug 1977 | 0.61 | 0.53 |
| | 16 Nov 1977 | 0.40 | 0.32 |

(Continued)

* A "B" following river mile indicates that a sample was taken where flow is split through a secondary channel.

(Sheet 2 of 7)

Table F19 (Continued)

| River Mile | Date | Average Grain Size $D_{65}$, mm | $D_{50}$, mm |
|---|---|---|---|
| 868.3 | 17 Jul 1969 | 0.55 | 0.48 |
| | October 1969 | 0.64 | 0.55 |
| | 26 May 1970 | 0.60 | 0.42 |
| | 30 Oct 1970 | 0.33 | 0.29 |
| | 6 Aug 1974 | 0.56 | 0.48 |
| | November 1974 | 0.54 | 0.41 |
| | October 1975 | 0.51 | 0.41 |
| | May 1976 | 0.44 | 0.37 |
| | 12 Nov 1976 | 0.55 | 0.49 |
| | 27 Jul 1977 | 0.67 | 0.55 |
| | 21 Dec 1977 | 0.55 | 0.39 |
| 864.8 | 17 Jul 1969 | 0.68 | 0.54 |
| | October 1969 | 0.37 | 0.32 |
| | 26 May 1970 | 0.59 | 0.54 |
| | 29 Oct 1970 | 0.65 | 0.54 |
| | 22 Nov 1971 | 0.57 | 0.49 |
| | 6 Aug 1974 | 0.71 | 0.56 |
| | October 1975 | 0.55 | 0.49 |
| | May 1976 | 0.62 | 0.51 |
| | 16 Nov 1976 | 0.63 | 0.52 |
| | 29 Jul 1977 | 0.49 | 0.43 |
| 855.4 | 15 Nov 1974 | 0.88 | 0.68 |
| | 23 Sep 1975 | 1.06 | 0.82 |
| | 24 May 1976 | 3.45 | 1.55 |
| | 24 Feb 1977 | 5.05 | 3.97 |
| | 24 Feb 1978 | 0.80 | 0.66 |
| 851.8 | 15 Nov 1974 | 0.67 | 0.53 |
| | 23 Nov 1975 | 0.61 | 0.46 |
| | 24 May 1976 | 0.78 | 0.62 |
| | 25 Aug 1977 | 0.98 | 0 71 |
| | 23 Feb 1978 | 0.61 | 0 48 |
| 849.0 | 14 Nov 1974 | 0 62 | 0.52 |
| | 23 Nov 1975 | 0.73 | 0 53 |
| | 25 May 1976 | 0.85 | 0.65 |
| | 25 Aug 1977 | 0.70 | 0.48 |
| | 23 Feb 1978 | 0.93 | 0.69 |

(Continued)

(Sheet 3 of 7)

Table F19 (Continued)

| River Mile | Date | Average Grain Size $D_{65}$, mm | $D_{50}$, mm |
|---|---|---|---|
| 839.6 | December 1969 | 0.73 | 0.58 |
| | 19 May 1970 | 0.82 | 0.68 |
| | 15 Oct 1970 | 0.44 | 0.34 |
| | 7 May 1971 | 0.69 | 0.54 |
| | November 1974 | 0.27 | 0.23 |
| | 24 Jul 1975 | 0.37 | 0.34 |
| | 29 Oct 1975 | 0.29 | 0.26 |
| | 27 May 1976 | 0.50 | 0.45 |
| | 24 May 1977 | 0.48 | 0.52 |
| | 7 Feb 1978 | 0.66 | 0.52 |
| 819.0 | 27 Apr 1970 | 0.62 | 0.52 |
| | 5 Jan 1971 | 0.51 | 0.43 |
| | 21 Jun 1971 | 0.57 | 0.48 |
| | 9 Sep 1971 | 0.61 | 0.52 |
| | 12 Jun 1972 | 0.50 | 0.41 |
| | 18 Mar 1974 | 0.59 | 0.51 |
| | 29 May 1974 | 0.62 | 0.52 |
| | 19 Dec 1974 | 1.74 | 1.33 |
| | 31 Jul 1975 | 0.91 | 0.74 |
| | 1 Dec 1975 | 1.59 | 1.09 |
| | 27 Aug 1976 | 0.69 | 0.58 |
| | 15 Aug 1977 | 3.23 | 1.89 |
| 817.1 | December 1969 | 0.52 | 0.44 |
| | 27 Apr 1970 | 0.64 | 0.52 |
| | 5 Jan 1971 | 0.57 | 0 49 |
| | 22 Jun 1971 | 0.51 | 0.43 |
| | 10 Sep 1971 | 0.47 | 0.40 |
| | 12 Jun 1972 | 0.57 | 0.50 |
| | 18 Mar 1974 | 0.58 | 0.50 |
| | 29 May 1974 | 0.61 | 0.51 |
| | 19 Dec 1974 | 0.81 | 0.66 |
| | 31 Jul 1975 | 0.73 | 0.61 |
| | 1 Dec 1975 | 0.61 | 0.55 |
| | 27 Aug 1976 | 0.89 | 0.74 |
| | 15 Aug 1977 | 1.20 | 0.95 |

(Continued)

(Sheet 4 of 7)

Table F19 (Continued)

| River Mile | Date | Average Grain Size $D_{65}$, mm | $D_{50}$, mm |
|---|---|---|---|
| 816.6 | 28 Mar 1974 | 0.49 | 0.44 |
| | 29 May 1974 | 0.59 | 0.50 |
| | 19 Dec 1974 | 0.67 | 0.58 |
| | 31 Jul 1975 | 0.67 | 0.57 |
| | 1 Dec 1975 | 0.81 | 0.62 |
| | 27 Aug 1976 | 0.77 | 0.65 |
| | 15 Aug 1977 | 0.60 | 0.53 |
| 798 J | 23 Jul 1969 | 0.83 | 0.68 |
| | 2 Dec 1969 | 0.61 | 0.51 |
| | 4 May 1970 | 0.82 | 0.68 |
| | 17 Nov 1970 | 0.85 | 0.44 |
| | 26 May 1971 | 0.70 | 0.59 |
| | 28 Jun 1972 | 0.83 | 0.62 |
| | 27 Nov 1974 | 0.56 | 0.48 |
| | 11 Jul 1975 | 0.89 | 0.64 |
| | 12 Dec 1975 | 0.55 | 0.47 |
| | 9 Aug 1977 | 0.56 | 0.48 |
| | 22 Feb 1978 | 0.65 | 0.53 |
| 792.2 | 23 Jul 1969 | 0.52 | 0.46 |
| | 2 Dec 1969 | 0.67 | 0.58 |
| | 4 Dec 1974 | 1.18 | 0.86 |
| | 10 Jul 1975 | 1.11 | 0.76 |
| | 12 Dec 1975 | 0.61 | 0.51 |
| | 9 Aug 1977 | 0.58 | 0.52 |
| | 22 Feb 1978 | 0.94 | 0.72 |
| 789.0 | 23 Jul 1969 | 0.55 | 0.47 |
| | 2 Dec 1969 | 0.32 | 0.28 |
| | 4 May 1970 | 0.65 | 0.54 |
| | 16 Nov 1970 | 0.45 | 0.40 |
| | 25 May 1971 | 0.56 | 0.46 |
| | 28 Jun 1972 | 0.80 | 0.64 |
| | 4 Dec 1974 | 0.52 | 0.46 |
| | 10 Jul 1975 | 0.47 | 0.39 |
| | 12 Dec 1974 | 0.56 | 0.44 |
| | 10 Aug 1977 | 0.50 | 0.40 |
| | 22 Feb 1978 | 0.45 | 0.35 |
| 743.6 | 9 Sep 1969 | 0 73 | 0.65 |
| 699.3 | 29 Jul 1977 | 0.63 | 0.53 |

(Continued)

(Sheet 5 of 7)

Table F19 (Continued)

| River Mile | Date | Average Grain Size $D_{65}$, mm | $D_{50}$, mm |
|---|---|---|---|
| 698.6 | 29 Jul 1977 | 0.53 | 0.46 |
| 697.7 | 29 Jul 1977 | 0.51 | 0.44 |
| 691.6 | 22 Jun 1970 | 0.60 | 0.52 |
| | 24 Sep 1970 | 0.39 | 0.34 |
| | 25 Jun 1971 | 0.75 | 0.62 |
| | 13 Jun 1972 | 0.73 | 0.60 |
| | 10 Jun 1974 | 0.39 | 0.36 |
| | 26 Nov 1974 | 5.23 | 4.31 |
| | 11 Nov 1975 | 0.58 | 0.51 |
| | 2 Jun 1976 | 0.60 | 0.49 |
| | 8 Nov 1976 | 0.98 | 0.73 |
| | 17 May 1977 | 1.04 | 0.71 |
| | 30 Nov 1977 | 0.56 | 0.45 |
| 685.6 | 12 Aug 1969 | 0.75 | 0.63 |
| | October 1969 | 0.54 | 0.41 |
| 643.5 | 22 Jan 1970 | 0.57 | 0.48 |
| 641.0 | 3 Oct 1974 | 0.30 | 0.19 |
| | 14 Aug 1975 | 0.18 | 0.17 |
| | 18 Nov 1975 | 0.19 | 0.16 |
| | 27 May 1976 | 0.26 | 0.23 |
| | 19 Oct 1976 | 0.23 | 0.21 |
| | 2 Jun 1977 | 0.26 | 0.24 |
| | 16 Nov 1977 | 0.18 | 0.15 |
| 638.2 | 30 Sep 1974 | 0.65 | 0.58 |
| | 14 Aug 1975 | 1.40 | 2.80 |
| | 19 Nov 1975 | 1.27 | 0.86 |
| | 26 May 1976 | 8.00 | 5.50 |
| | 19 Oct 1976 | 0.90 | 0.75 |
| | 3 Jun 1977 | 1.20 | 0.90 |
| | 16 Nov 1977 | 8.00 | 5.50 |
| 635.2 | 13 Jun 1970 | 0.51 | 0.46 |
| | 9 Nov 1970 | 0.52 | 0.46 |
| | 8 Jun 1971 | 0.48 | 0.41 |
| | 15 Sep 1971 | 0.46 | 0.41 |
| | 2 May 1972 | 0.35 | 0.30 |
| | 1 Oct 1974 | 0.41 | 0.36 |

(Continued)

(Sheet 6 of 7)

Table F19 (Concluded)

| River Mile | Date | Average Grain Size $D_{65}$, mm | $D_{50}$, mm |
|---|---|---|---|
| 635.2 (Continued) | 15 Aug 1975 | 0.37 | 0.34 |
| | 19 Nov 1975 | 0.43 | 0.36 |
| | 25 May 1976 | 0.38 | 0.33 |
| | 19 Oct 1976 | 0.35 | 0.24 |
| | 3 Jun 1977 | 0.43 | 0.37 |
| | 16 Nov 1977 | 0.38 | 0.33 |
| 619.6 | 6 Jun 1970 | 0.41 | 0.35 |
| | 21 Sep 1970 | 0.51 | 0.43 |
| | 17 May 1971 | 0.55 | 0.47 |
| | 7 Apr 1972 | 0.50 | 0.42 |
| | 24 Jun 1975 | 0.24 | 0.32 |
| | 5 Nov 1975 | 0.35 | 0.32 |
| | 29 Jul 1976 | 0.38 | 0.35 |
| | 21 Jul 1977 | 0.54 | 0.47 |

(Sheet 7 of 7)

Table F20

$D_{84}$, $D_{50}$, and $D_{16}$ Sizes of Bed-Material Samples (mm) Collected on the Lower Mississippi River by U. S. Army Engineer District, Vicksburg*

| Potomology Study Reaches | | Calendar Year 1932/1934 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cessions-Henrico** (miles 616.0 - 606.0) | No. of Samples | 5 | 5 | -- | -- | -- | -- | -- | 4 | 19 | 7 |
| | $D_{84}$ | 0.685 | 0.713 | -- | -- | -- | -- | -- | 0.528 | 0.560 | 0.402 |
| | $D_{50}$ | 0.378 | 0.410 | -- | -- | -- | -- | -- | 0.335 | 0.371 | 0.266 |
| | $D_{16}$ | 0.168 | 0.247 | -- | -- | -- | -- | -- | 0.213 | 0.232 | 0.149 |
| Smith Point-Terrene (miles 606.0 - 594.2) | No. of Samples | 3 | 4 | -- | 15 | 136 | 29 | 28 | 28 | 21 | 6 |
| | $D_{84}$ | 0.541 | 0.589 | -- | 0.670 | 0.581 | 0.656 | 0.540 | 0.517 | 0.586 | 0.537 |
| | $D_{50}$ | 0.296 | 0.420 | -- | 0.364 | 0.368 | 0.377 | 0.330 | 0.300 | 0.324 | 0.217 |
| | $D_{16}$ | 0.174 | 0.258 | -- | 0.209 | 0.208 | 0.211 | 0.201 | 0.085 | 0.028 | 0.003 |
| Terrene-Ozark (miles 594.2 - 581.0) | No. of Samples | 19 | 24 | 28 | 70 | 55 | 44 | 23 | 28 | 47 | 16 |
| | $D_{84}$ | 1.651 | 0.561 | 0.709 | 0.551 | 0.527 | 0.525 | 0.519 | 0.438 | 0.472 | 0.534 |
| | $D_{50}$ | 0.361 | 0.365 | 0.379 | 0.349 | 0.349 | 0.331 | 0.302 | 0.263 | 0.303 | 0.315 |
| | $D_{16}$ | 0.169 | 0.232 | 0.251 | 0.211 | 0.222 | 0.176 | 0.169 | 0.123 | 0.157 | 0.007 |
| Ozark-Eutaw (miles 581.0 - 565.9) includes Arkansas City discharge range | No. of Samples | 17 | 20 | 40 | 111 | 76 | 91 | 66 | 243 | 312 | 284 |
| | $D_{84}$ | 1.088 | 0.539 | 0.671 | 0.637 | 0.587 | 0.558 | 0.685 | 0.491 | 0.540 | 0.568 |
| | $D_{50}$ | 0.357 | 0.356 | 0.362 | 0.357 | 0.354 | 0.353 | 0.339 | 0.331 | 0.345 | 0.299 |
| | $D_{16}$ | 0.098 | 0.225 | 0.237 | 0.226 | 0.213 | 0.236 | 0.230 | 0.225 | 0.226 | 0.209 |
| Choctaw Bar (miles 565.9 - 550.4) | No. of Samples | 14 | 8 | 86 | 75 | 109 | 76 | 23 | 49 | 38 | 22 |
| | $D_{84}$ | 0.704 | 0.700 | 0.632 | 0.665 | 0.555 | 0.558 | 0.530 | 0.556 | 0.524 | 0.440 |
| | $D_{50}$ | 0.375 | 0.392 | 0.347 | 0.373 | 0.349 | 0.345 | 0.350 | 0.362 | 0.366 | 0.287 |
| | $D_{16}$ | 0.217 | 0.244 | 0.220 | 0.245 | 0.219 | 0.222 | 0.220 | 0.230 | [illegible] | [illegible] |
| Greenville (miles 550.4 - 531.2) | No. of Samples | 53 | 48 | 73 | 104 | 123 | 54 | 49 | 7 | 39 | 9 |
| | $D_{84}$ | 0.897 | 0.506 | 0.581 | 0.541 | 0.528 | 0.537 | 0.558 | 0.577 | 0.576 | 0.417 |
| | $D_{50}$ | 0.399 | 0.326 | 0.367 | 0.341 | 0.338 | 0.336 | 0.364 | 0.393 | 0.338 | 0.254 |
| | $D_{16}$ | 0.233 | 0.193 | 0.240 | 0.192 | 0.204 | 0.185 | 0.242 | 0.251 | 0.216 | 0.156 |
| Lakeport (miles 531.2 - 524.2) | No. of Samples | 6 | 4 | 21 | 38 | 41 | 19 | 24 | 2 | 6 | 18 |
| | $D_{84}$ | 4.213 | 0.702 | 0.549 | 0.545 | 0.543 | 0.547 | 0.529 | 0.531 | 0.455 | 0.423 |
| | $D_{50}$ | 0.426 | 0.417 | 0.344 | 0.351 | 0.317 | 0.323 | 0.351 | 0.311 | 0.292 | 0.299 |
| | $D_{16}$ | 0.231 | 0.292 | 0.231 | 0.229 | 0.151 | 0.175 | 0.233 | 0.217 | 0.213 | 0.189 |
| Kentucky Bend (miles 524.2 - 514.8) | No. of Samples | 8 | 4 | 27 | 69 | 75 | 52 | 68 | 2 | 8 | 9 |
| | $D_{84}$ | 0.780 | 0.516 | 0.586 | 0.552 | 0.544 | 0.671 | 0.631 | 0.542 | 0.481 | 0.523 |
| | $D_{50}$ | 0.418 | 0.356 | 0.385 | 0.343 | 0.353 | 0.385 | 0.376 | 0.351 | 0.326 | 0.329 |
| | $D_{16}$ | 0.242 | 0.240 | 0.265 | 0.202 | 0.228 | 0.235 | 0.245 | 0.239 | 0.226 | 0.218 |
| Cracraft-Carolina (miles 514.8 - 506.6) | No. of Samples | 10 | 68 | 35 | 74 | 58 | 18 | 38 | 2 | 6 | 5 |
| | $D_{84}$ | 3.011 | 0.533 | 0.635 | 0.601 | 0.523 | 0.421 | 0.509 | 0.408 | 0.578 | 0.379 |
| | $D_{50}$ | 0.385 | 0.332 | 0.377 | 0.353 | 0.320 | 0.300 | 0.327 | 0.309 | 0.338 | 0.245 |
| | $D_{16}$ | 0.234 | 0.192 | 0.230 | 0.212 | 0.210 | 0.214 | 0.203 | 0.220 | 0.220 | 0.021 |
| Carolina-Baleshed (miles 506.6 - 495.6) | No. of Samples | 11 | -- | 8 | 43 | 35 | 11 | 27 | 7 | 20 | 20 |
| | $D_{84}$ | 0.395 | -- | 2.196 | 0.745 | 0.646 | 0.513 | 0.470 | 0.779 | [illegible] | 0.584 |
| | $D_{50}$ | 0.267 | -- | 0.530 | 0.399 | 0.385 | 0.318 | 0.295 | 0.383 | 0.305 | 0.314 |
| | $D_{16}$ | 0.198 | -- | 0.267 | 0.260 | 0.261 | 0.202 | 0.173 | 0.237 | 0.201 | 0.167 |
| Baleshed Landing (miles 495.6 - 485.6) | No. of Samples | 15 | 27 | 53 | 105 | 59 | 43 | 78 | 3 | 8 | 10 |
| | $D_{84}$ | 0.597 | 0.621 | 0.569 | 0.548 | 0.527 | 0.546 | 0.517 | 0.514 | 0.504 | 0.576 |
| | $D_{50}$ | 0.378 | 0.389 | 0.337 | 0.348 | 0.341 | 0.346 | 0.304 | 0.331 | 0.324 | 0.374 |
| | $D_{16}$ | 0.222 | 0.228 | 0.222 | 0.227 | 0.221 | 0.220 | 0.162 | 0.227 | 0.214 | 0.237 |
| Ajax Bar (miles 485.6 - 479.8) | No. of Samples | 3 | 118 | 20 | 55 | 29 | 23 | 37 | 9 | 17 | 28 |
| | $D_{84}$ | 17.670 | 0.524 | 0.592 | 0.492 | 0.418 | 0.457 | 0.480 | 0.479 | 0.523 | 0.543 |
| | $D_{50}$ | 0.477 | 0.335 | 0.354 | 0.320 | 0.292 | 0.306 | 0.298 | 0.271 | 0.301 | 0.314 |
| | $D_{16}$ | 0.293 | 0.220 | 0.227 | 0.214 | 0.148 | 0.165 | 0.180 | 0.146 | 0.193 | 0.191 |

(Continued)

* Source: Reference 48.

Table F20 (Concluded)

| Potomology Study Reaches | | Calendar Year 1932/1934 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ajax-Cottonwood (miles 479.8 - 472.0) | No. of Samples | 6 | -- | -- | 9 | 33 | 15 | 29 | 1 | 6 | 7 |
| | $D_{84}$ | 0.818 | -- | -- | 0.497 | 0.524 | 0.514 | 0.653 | 0.384 | 0.494 | 0.471 |
| | $D_{50}$ | 0.464 | -- | -- | 0.343 | 0.317 | 0.323 | 0.337 | 0.253 | 0.144 | 0.106 |
| | $D_{16}$ | 0.272 | -- | -- | 0.236 | 0.185 | 0.167 | 0.169 | 0.184 | 0.027 | 0.002 |
| Cottonwood Bar (miles 472.0 - 467.8) | No. of Samples | 3 | 12 | 35 | 43 | 62 | 17 | 29 | 3 | 7 | 7 |
| | $D_{84}$ | 0.513 | 0.643 | 0.708 | 0.545 | 0.514 | 0.528 | 0.491 | 0.407 | 0.489 | 0.510 |
| | $D_{50}$ | 0.329 | 0.431 | 0.355 | 0.304 | 0.327 | 0.263 | 0.322 | 0.214 | 0.276 | 0.341 |
| | $D_{16}$ | 0.224 | 0.244 | 0.217 | 0.184 | 0.214 | 0.162 | 0.199 | 0.139 | 0.179 | 0.230 |
| Cottonwood-Belle Island (miles 467.8 - 461.4) | No. of Samples | 8 | -- | 8 | 15 | 3 | 5 | 12 | 5 | 9 | 11 |
| | $D_{84}$ | 0.723 | -- | 0.540 | 0.661 | 0.401 | 0.906 | 1.395 | 0.468 | 0.571 | 0.695 |
| | $D_{50}$ | 0.418 | -- | 0.268 | 0.332 | 0.278 | 0.365 | 0.357 | 0.221 | 0.348 | 0.374 |
| | $D_{16}$ | 0.221 | -- | 0.163 | 0.201 | 0.188 | 0.194 | 0.224 | 0.004 | 0.217 | 0.196 |
| Belle Island-Milliken Bend (miles 461.4 - 451.8) | No. of Samples | 10 | 4 | 16 | 18 | 27 | 11 | 16 | 9 | 2 | 3 |
| | $D_{84}$ | 19.044 | 0.578 | 0.546 | 0.566 | 0.564 | 0.541 | 0.545 | 0.977 | 20.542 | 0.634 |
| | $D_{50}$ | 0.577 | 0.353 | 0.373 | 0.364 | 0.361 | 0.350 | 0.353 | 0.407 | 0.547 | 0.392 |
| | $D_{16}$ | 0.342 | 0.223 | 0.260 | 0.229 | 0.219 | 0.181 | 0.227 | 0.216 | 0.311 | 0.237 |
| Milliken Bend-Vicksburg (miles 451.8 - 435.0) includes Vicksburg discharge range | No. of Samples | 37 | -- | -- | 89 | 89 | 80 | 87 | 237 | 397 | 255 |
| | $D_{84}$ | 1.051 | -- | -- | 0.539 | 0.588 | 0.799 | 0.638 | 0.673 | 1.052 | 0.720 |
| | $D_{50}$ | 0.371 | -- | -- | 0.346 | 0.379 | 0.395 | 0.392 | 0.404 | 0.489 | 0.422 |
| | $D_{16}$ | 0.195 | -- | -- | 0.200 | 0.224 | 0.248 | 0.235 | 0.265 | 0.324 | 0.256 |
| Racetrack Towhead (miles 435.0 - 422.8) | No. of Samples | 23 | 9 | -- | 4 | 8 | 8 | 8 | 11 | 10 | 16 |
| | $D_{84}$ | 0.530 | 0.456 | -- | 0.532 | 1.565 | 0.556 | 0.582 | 0.468 | 0.401 | 0.379 |
| | $D_{50}$ | 0.313 | 0.294 | -- | 0.326 | 0.409 | 0.324 | 0.345 | 0.294 | 0.248 | 0.241 |
| | $D_{16}$ | 0.191 | 0.182 | -- | 0.225 | 0.285 | 0.219 | 0.198 | 0.207 | 0.154 | 0.158 |
| Point Pleasant (miles 422.8 - 407.4) | No. of Samples | 13 | 13 | -- | -- | -- | 104 | 144 | 17 | 12 | 16 |
| | $D_{84}$ | 0.533 | 0.529 | -- | -- | -- | 0.631 | 0.521 | 0.485 | 0.432 | 0.545 |
| | $D_{50}$ | 0.256 | 0.351 | -- | -- | -- | 0.353 | 0.310 | 0.249 | 0.210 | 0.308 |
| | $D_{16}$ | 0.094 | 0.234 | -- | -- | -- | 0.194 | 0.174 | 0.147 | 0.003 | 0.088 |
| Grand Gulf (miles 407.4 - 395.2) | No. of Samples | 6 | -- | -- | -- | -- | 57 | 62 | 4 | 5 | 6 |
| | $D_{84}$ | 0.577 | -- | -- | -- | - | 0.466 | 0.504 | 0.517 | 0.54 | 0.721 |
| | $D_{50}$ | 0.310 | -- | -- | -- | -- | 0.302 | 0.286 | 0.325 | 0.331 | 0.306 |
| | $D_{16}$ | 0.134 | -- | -- | -- | -- | 0.192 | 0.148 | 0.162 | 0.217 | 0.214 |
| Rodney (miles 395.2 - 381.4) | No. of Samples | 5 | 3 | -- | 52 | 107 | 90 | 43 | 51 | 14 | 22 |
| | $D_{84}$ | 3.394 | 0.367 | -- | 0.514 | 0.551 | 0.598 | 0.531 | 0.488 | 0.498 | 0.378 |
| | $D_{50}$ | 0.451 | 0.258 | -- | 0.307 | 0.328 | 0.349 | 0.302 | 0.290 | 0.310 | 0.229 |
| | $D_{16}$ | 0.279 | 0.186 | -- | 0.209 | 0.209 | 0.209 | 0.178 | 0.169 | 0.181 | 0.029 |
| Waterproof (miles 381.4 - 368.2) | No. of Samples | 4 | 4 | -- | -- | -- | 63 | 21 | 66 | 6 | 10 |
| | $D_{84}$ | 0.540 | 0.414 | -- | -- | -- | 0.403 | 0.407 | 0.404 | 0.469 | 0.390 |
| | $D_{50}$ | 0.320 | 0.330 | -- | -- | -- | 0.257 | 0.275 | 0.277 | 0.256 | 0.267 |
| | $D_{16}$ | 0.199 | 0.217 | -- | -- | -- | 0.159 | 0.174 | 0.173 | 0.164 | 0.177 |
| Natchez (miles 368.2 - 355.2) includes Natchez discharge range | No. of Samples | 10 | -- | -- | -- | -- | 76 | 31 | 298 | 384 | 260 |
| | $D_{84}$ | 0.576 | -- | -- | -- | -- | 0.489 | 0.499 | 0.523 | 0.574 | 0.616 |
| | $D_{50}$ | 0.320 | -- | -- | -- | -- | 0.314 | 0.307 | 0.336 | 0.394 | 0.398 |
| | $D_{16}$ | 0.214 | -- | -- | -- | -- | 0.208 | 0.169 | 0.217 | 0.273 | 0.244 |
| St. Catherine (miles 355.2 - 338.6) | No. of Samples | 10 | -- | -- | -- | -- | -- | 22 | 80 | 13 | 10 |
| | $D_{84}$ | 0.497 | -- | -- | -- | -- | -- | 0.387 | 0.399 | 0.507 | 0.342 |
| | $D_{50}$ | 0.307 | -- | -- | -- | -- | -- | 0.251 | 0.254 | 0.279 | 0.158 |
| | $D_{16}$ | 0.160 | -- | -- | -- | -- | -- | 0.161 | 0.161 | 0.167 | 0.002 |
| Bougere (miles 338.6 - 320.4) | No. of Samples | 5 | -- | -- | -- | -- | -- | -- | 61 | 19 | 4 |
| | $D_{84}$ | 0.626 | -- | -- | -- | -- | -- | -- | 0.536 | 0.534 | 0.483 |
| | $D_{50}$ | 0.348 | -- | -- | -- | -- | -- | -- | 0.321 | 0.304 | 0.312 |
| | $D_{16}$ | 0.176 | -- | -- | -- | -- | -- | -- | 0.188 | 0.177 | 0.209 |

Table F21

Bed-Material Samples Collected on the Lower Mississippi River During 1975

by U. S. Army Engineer District, New Orleans*

| River Mile | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 | 0.004 |
| 325.0 | 100.0 | 99.4 | 83.6 | 14.8 | 1.1 | 0.2 | 0.1 | 0.1 | 0.0 | | | | |
| 315.0 | 100.0 | 99.8 | 99.3 | 86.7 | 16.3 | 1.8 | 0.3 | 0.2 | 0.0 | | | | |
| 305.0 | 99.4 | 80.9 | 27.8 | 3.7 | 3.7 | 1.3 | 0.8 | 0.2 | 0.0 | | | | |
| 295.0 | 99.9 | 96.8 | 68.5 | 12.1 | 2.2 | 0.3 | 0.1 | 0.0 | | | | | |
| 285.0 | 100.0 | 99.9 | 99.6 | 89.1 | 23.1 | 3.8 | 0.8 | 0.2 | 0.2 | | | | |
| 275.0 | 99.9 | 94.1 | 35.6 | 5.6 | 1.2 | 0.5 | 0.2 | 0.2 | 0.2 | | | | |
| 265.0 | 100.0 | 99.7 | 97.3 | 79.6 | 31.4 | 6.3 | 0.7 | 0.1 | 0.1 | | | | |
| 255.0 | 100.0 | 99.8 | 99.5 | 94.0 | 40.0 | 5.2 | 0.7 | 0.4 | 0.1 | | | | |
| 245.0 | 100.0 | 99.7 | 99.6 | 98.0 | 71.7 | 19.1 | 4.1 | 1.3 | 0.6 | | | | |
| 235.0 | 99.9 | 99.8 | 94.6 | 61.5 | 18.6 | 2.2 | 0.2 | 0.0 | | | | | |
| 223.0 | 100.0 | 99.9 | 97.9 | 60.5 | 11.3 | 1.6 | 0.8 | 0.3 | | | | | |
| 222.0 | 100.0 | 99.7 | 96.7 | 80.0 | 52.6 | 26.6 | 10.8 | 5.7 | 3.3 | | | | |
| 212.0 | 100.0 | 99.9 | 99.5 | 97.5 | 81.5 | 12.6 | 1.5 | 0.7 | 0.2 | | | | |
| 208.8 | 100.0 | 99.8 | 95.5 | 86.4 | 75.6 | 57.4 | 45.8 | 41.6 | 20.5 | 10.2 | 6.0 | 5.0 | 4.9 |
| 204.0 | 100.0 | 99.9 | 99.9 | 99.3 | 81.4 | 13.6 | 1.4 | 0.4 | 0.2 | | | | |
| 197.0 | 100.0 | 99.8 | 99.5 | 85.0 | 30.6 | 4.9 | 1.0 | 0.4 | 0.2 | | | | |

(Continued)

* Source: File information provided by U. S. Army Engineer District, New Orleans.

(Sheet 1 of 5)

Table F21 (Continued)

| River Mile | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 | 0.004 |
| 191.0 | 98.0 | 94.8 | 93.2 | 91.7 | 89.0 | 69.6 | 55.6 | 51.1 | 45.5 | 19.8 | 11.5 | 8.5 | 7.5 |
| 190.0 | 99.9 | 99.8 | 99.6 | 95.1 | 51.3 | 8.0 | 0.9 | 0.4 | 0.2 | | | | |
| 187.5 | 99.9 | 99.4 | 93.3 | 80.9 | 77.2 | 72.8 | 68.8 | 66.6 | 57.2 | 46.4 | 39.6 | 33.6 | 28.1 |
| 183.0 | 99.9 | 99.8 | 99.4 | 94.3 | 53.1 | 6.4 | 0.9 | 0.5 | 0.2 | | | | |
| 175.5 | 97.6 | 79.4 | 69.5 | 51.5 | 43.2 | 35.0 | 31.1 | 30.4 | 30.1 | 19.3 | 16.3 | 14.4 | 12.1 |
| 165.0 | 100.0 | 99.8 | 99.3 | 98.3 | 91.8 | 25.1 | 6.3 | 1.5 | 1.3 | | | | |
| 156.4 | 99.9 | 99.1 | 98.7 | 96.4 | 92.1 | 80.1 | 66.1 | 59.0 | 55.1 | 37.9 | 28.2 | 23.8 | 21.3 |
| 155.0 | 100.0 | 100.0 | 98.8 | 77.1 | 31.4 | 7.6 | 1.0 | 0.4 | 0.2 | | | | |
| 153.0 | 99.7 | 97.0 | 89.3 | 75.4 | 26.2 | 3.6 | 0.4 | 0.2 | 0.2 | | | | |
| 152.2 | 100.0 | 100.0 | 99.8 | 97.4 | 65.8 | 51.2 | 47.4 | 46.1 | 45.7 | 39.0 | 30.0 | 22.4 | 16.6 |
| 147.0 | 100.0 | 100.0 | 100.0 | 99.6 | 96.0 | 65.2 | 27.4 | 16.2 | 12.8 | | | | |
| 145.0 | 98.2 | 98.0 | 97.4 | 95.6 | 93.6 | 92.8 | 91.6 | 89.8 | 88.2 | 63.2 | 51.0 | 43.0 | 39.0 |
| 141.0 | 100.0 | 100.0 | 100.0 | 99.9 | 99.3 | 96.1 | 91.0 | 87.1 | 83.5 | 59.0 | 44.1 | 33.8 | 15.8 |
| 139.3 | 100.0 | 100.0 | 99.9 | 99.8 | 99.0 | 91.0 | 63.8 | 52.5 | 46.0 | 45.6 | 40.5 | 40.0 | 40.0 |
| 139.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 98.8 | 93.6 | 92.0 | 90.0 | 62.5 | 45.5 | 32.6 | 24.4 |
| 137.0 | 100.0 | 100.0 | 99.6 | 99.2 | 98.6 | 92.5 | 83.2 | 78.2 | 75.6 | 59.6 | 48.3 | 37.1 | 23.5 |
| 135.0 | 99.6 | 99.4 | 99.2 | 99.2 | 99.0 | 98.8 | 98.8 | 98.6 | 98.4 | 98.2 | 85.5 | 72.0 | 60.0 |
| 133.0 | 100.0 | 99.9 | 96.8 | 72.2 | 44.4 | 32.2 | 17.0 | 10.8 | 7.5 | | | | |
| 128.0 | 100.0 | 100.0 | 100.0 | 99.9 | 94.0 | 47.1 | 24.9 | 19.1 | 10.4 | 5.1 | 3.2 | 2.6 | 2.1 |
| 125.2 | 100.0 | 100.0 | 100.0 | 100.0 | 99.1 | 95.5 | 85.4 | 78.1 | 59.9 | 35.2 | 22.0 | 15.2 | 11.3 |

(Continued)

(Sheet 2 of 5)

Table F21 (Continued)

| River Mile | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 | 0.004 |
| 125.0 | 100.0 | 99.9 | 99.8 | 95.1 | 45.1 | 9.9 | 1.3 | 0.5 | 0.2 | | | | |
| 120.6 | 100.0 | 99.6 | 99.1 | 98.6 | 98.1 | 84.1 | 46.0 | 31.3 | 23.4 | | | | |
| 116.0 | 100.0 | 99.9 | 96.5 | 81.1 | 69.7 | 26.5 | 3.8 | 1.3 | 0.6 | | | | |
| 105.4 | 99.9 | 99.9 | 99.6 | 99.4 | 99.0 | 93.6 | 73.2 | 43.9 | 39.2 | 16.2 | 11.2 | 8.5 | 6.1 |
| 105.0 | 100.0 | 99.9 | 99.6 | 94.3 | 47.4 | 10.3 | 0.8 | 0.1 | 0.1 | | | | |
| 103.0 | 100.0 | 99.9 | 99.8 | 99.4 | 90.7 | 58.5 | 41.6 | 23.6 | 16.0 | 12.8 | 10.4 | 8.3 | 7.1 |
| 101.5 | 99.8 | 99.3 | 99.2 | 99.2 | 98.5 | 97.5 | 84.6 | 76.4 | 62.8 | 29.8 | 20.5 | 15.5 | 13.2 |
| 99.1 | 100.0 | 100.0 | 99.9 | 99.4 | 87.8 | 24.4 | 2.6 | 1.3 | 0.4 | | | | |
| 98.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.4 | 98.5 | 96.1 | 89.0 | 63.7 | 44.5 | 34.6 | 27.9 |
| 98.2 | 100.0 | 100.0 | 100.0 | 99.6 | 99.5 | 99.0 | 95.5 | 92.0 | 87.5 | 70.0 | 52.5 | 43.0 | 37.0 |
| 96.7 | 100.0 | 100.0 | 100.0 | 99.8 | 99.7 | 98.8 | 96.8 | 94.6 | 91.8 | 65.6 | 45.8 | 37.2 | 30.6 |
| 95.8 | 100.0 | 100.0 | 99.8 | 99.8 | 99.6 | 85.6 | 55.0 | 45.6 | 32.9 | 28.4 | 18.2 | 14.3 | 12.2 |
| 95.3 | 100.0 | 99.6 | 99.0 | 97.5 | 95.3 | 91.3 | 82.0 | 76.4 | 65.0 | 18.0 | 12.0 | 8.7 | 7.0 |
| 95.1 | 100.0 | 100.0 | 100.0 | 99.9 | 99.4 | 98.2 | 89.2 | 79.5 | 65.8 | 38.8 | 29.1 | 23.4 | 9.8 |
| 95.0 | 100.0 | 99.6 | 99.0 | 93.8 | 57.0 | 24.4 | 16.0 | 14.6 | 14.4 | | | | |
| 94.7 | 100.0 | 99.8 | 99.8 | 98.0 | 96.8 | 72.5 | 27.1 | 16.5 | 11.4 | | | | |
| 92.7 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 99.4 | 98.2 | 95.8 | 83.5 | 65.5 | 52.2 | 39.2 |
| 90.6 | 99.9 | 99.8 | 99.4 | 99.4 | 99.3 | 98.8 | 98.6 | 98.3 | 97.8 | 84.0 | 69.5 | 57.3 | 35.4 |
| 89.9 | 100.0 | 100.0 | 99.8 | 99.6 | 98.2 | 96.7 | 91.2 | 86.5 | 84.6 | 43.5 | 30.8 | 23.6 | 19.6 |
| 88.3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 99.7 | 96.1 | 95.2 | 82.5 | 55.0 | 45.1 | 36.0 |

(Continued)

(Sheet 3 of 5)

Table F21 (Continued)

| River Mile | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 | 0.004 |
| 87.9 | 100.0 | 100.0 | 100.0 | 99.9 | 99.3 | 97.8 | 93.1 | 87.0 | 83.2 | 42.2 | 25.6 | 18.1 | 15.0 |
| 81.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.4 | 98.4 | 93.6 | 88.2 | 86.4 | 58.9 | 40.8 | 29.4 | 21.4 |
| 75.8 | 100.0 | 100.0 | 100.0 | 100.0 | 99.6 | 95.0 | 81.3 | 72.0 | 68.8 | 30.0 | 22.0 | 18.1 | 14.5 |
| 75.2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.4 | 96.5 | 92.0 | 87.5 | 52.0 | 40.0 | 31.0 | 23.2 |
| 75.0 | 100.0 | 99.4 | 85.9 | 31.5 | 5.9 | 1.2 | 0.3 | 0.1 | 0.1 | | | | |
| 71.9 | 100.0 | 100.0 | 100.0 | 100.0 | 95.0 | 80.5 | 67.0 | 58.8 | 16.8 | 11.5 | 7.8 | 6.5 | 1.2 |
| 68.0 | 100.0 | 100.0 | 99.9 | 99.7 | 93.2 | 63.6 | 47.3 | 40.9 | 34.3 | 19.2 | 26.8 | 10.4 | 9.2 |
| 65.0 | 100.0 | 100.0 | 99.4 | 99.2 | 97.6 | 96.4 | 96.0 | 95.6 | 95.4 | 87.0 | 76.8 | 66.2 | 52.8 |
| 62.8 | 100.0 | 100.0 | 100.0 | 100.0 | 99.7 | 88.3 | 76.7 | 74.5 | 72.8 | 58.4 | 48.5 | 41.8 | 37.0 |
| 59.7 | 99.7 | 99.4 | 99.3 | 98.9 | 97.3 | 81.9 | 43.6 | 30.6 | 22.8 | 7.7 | 4.6 | 4.2 | 4.0 |
| 55.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 97.8 | 84.8 |
| 51.0 | 100.0 | 99.9 | 96.5 | 83.7 | 77.6 | 75.6 | 70.6 | 66.0 | 54.4 | 35.4 | 28.0 | 21.4 | 16.1 |
| 49.2 | 100.0 | 100.0 | 100.0 | 99.8 | 99.4 | 98.6 | 95.4 | 92.2 | 89.5 | 51.2 | 31.8 | 23.0 | 18.5 |
| 45.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.3 | 96.2 | 87.5 | 72.3 |
| 35.0 | 99.4 | 99.2 | 99.0 | 97.8 | 86.7 | 15.7 | 2.0 | 0.6 | 0.3 | | | | |
| 33.2 | 100.0 | 99.9 | 99.8 | 99.5 | 97.0 | 78.8 | 68.9 | 65.5 | 64.8 | 51.1 | 44.8 | 38.9 | 33.6 |
| 33.0 | 100.0 | 99.8 | 99.3 | 99.0 | 98.8 | 93.0 | 84.1 | 66.2 | 63.2 | 25.2 | 17.8 | 13.8 | 11.4 |
| 30.0 | 100.0 | 100.0 | 100.0 | 99.9 | 99.6 | 98.9 | 96.1 | 95.5 | 93.0 | 82.1 | 71.9 | 55.4 | 39.1 |
| 29.5 | 100.0 | 99.9 | 99.4 | 99.1 | 98.4 | 85.9 | 50.8 | 33.8 | 22.3 | | | | |
| 25.2 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 97.0 | 90.8 | 81.2 | 73.0 | 47.2 | 36.0 | 29.4 | 23.0 |

(Continued)

(Sheet 4 of 5)

Table F21 (Concluded)

| | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Mile | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 | 0.004 |
| 25.0 | 100.0 | 99.6 | 99.6 | 99.6 | 99.6 | 98.2 | 82.4 | 76.8 | 75.8 | 49.9 | 39.0 | 31.9 | 25.2 |
| 18.6 | 100.0 | 99.8 | 99.8 | 99.5 | 98.8 | 85.2 | 48.9 | 48.0 | 46.8 | 38.8 | 24.5 | 17.0 | 13.8 |
| 15.0 | 99.5 | 98.4 | 97.8 | 91.7 | 38.9 | 6.2 | 0.9 | 0.5 | 0.5 | | | | |
| 10.5 | 100.0 | 100.0 | 100.0 | 100.0 | 99.9 | 97.1 | 83.6 | 76.0 | 66.2 | 55.3 | 49.4 | 44.0 | 37.7 |
| 5.0 | 100.0 | 100.0 | 99.8 | 87.9 | 27.2 | 1.9 | 0.4 | 0.1 | 0.1 | | | | |
| 4.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 96.7 | 93.8 | 88.5 | 40.5 | 26.2 | 21.6 | 15.9 |
| 3.5 | 100.0 | 99.9 | 99.8 | 99.8 | 99.5 | 99.0 | 98.4 | 97.6 | 96.8 | 83.7 | 64.1 | 50.3 | 37.0 |
| 0.0 | 100.0 | 99.8 | 99.6 | 98.8 | 79.2 | 55.5 | 28.8 | 22.8 | 21.2 | 16.0 | 15.4 | 13.1 | 10.9 |

(Sheet 5 of 5)

Table F22

Bed-Material Samples Collected on the Atchafalaya River from 1975 through 1977 by U. S. Army Engineer District, New Orleans*

| River Mile | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.41 | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 |
| 0.0 | 98.5 | 98.3 | 81.2 | 41.9 | 16.4 | 5.1 | 1.0 | 0.2 | 0.1 | 0.0 | | | |
| 10.0 | 99.4 | 99.3 | 90.7 | 59.3 | 17.6 | 4.0 | 0.9 | 0.2 | 0.2 | 0.1 | | | |
| 20.0 | 98.6 | 98.1 | 88.9 | 69.2 | 37.6 | 17.2 | 3.8 | 0.6 | 0.3 | 0.2 | | | |
| 30.0 | 99.7 | 99.6 | 94.6 | 75.3 | 51.2 | 34.0 | 28.5 | 26.2 | 25.6 | 23.8 | | | |
| 40.0 | 96.9 | 96.3 | 85.2 | 68.4 | 46.0 | 22.8 | 15.9 | 13.7 | 12.5 | 11.0 | | | |
| 50.0 | 100.0 | 99.3 | 98.8 | 97.4 | 80.6 | 26.4 | 21.9 | 17.3 | 16.4 | 15.6 | | | |
| 60.0 | 98.5 | 98.1 | 94.3 | 85.3 | 66.6 | 45.5 | 38.0 | 36.5 | 35.8 | 35.3 | | | |
| 70.0 | 99.8 | 99.6 | 95.0 | 87.4 | 57.0 | 52.5 | 38.7 | 32.3 | 29.6 | 28.1 | | | |
| 75.0 | 100.0 | 100.0 | 99.6 | 94.2 | 54.5 | 36.6 | 32.1 | 30.9 | 30.8 | 30.5 | | | |
| 80.0 | 100.0 | 99.9 | 99.0 | 93.3 | 64.7 | 30.9 | 20.6 | 18.9 | 18.5 | 18.0 | | | |
| 85.0 | 99.8 | 99.7 | 97.3 | 82.5 | 47.5 | 8.4 | 1.5 | 1.0 | 0.9 | 0.8 | | | |
| 90.0 | 100.0 | 99.4 | 98.2 | 95.4 | 78.4 | 48.0 | 30.7 | 29.1 | 28.9 | 28.6 | | | |
| 95.0 | 100.0 | 100.0 | 99.8 | 98.6 | 81.2 | 40.8 | 13.0 | 10.3 | 9.8 | 9.6 | | | |
| 100.0 | 100.0 | 99.4 | 97.9 | 94.6 | 75.9 | 35.7 | 17.7 | 15.6 | 15.1 | 14.8 | | | |
| 105.0 | 100.0 | 99.6 | 98.9 | 96.8 | 92.2 | 68.9 | 38.0 | 30.5 | 29.2 | 28.6 | | | |

(Continued)

* File information provided by U. S. Army Engineer District, New Orleans.

Table F22 (Concluded)

| River Mile | Average "Percent Finer Than" Values for Selected Sieve Sizes, mm | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.41 | 1.00 | 0.50 | 0.35 | 0.25 | 0.177 | 0.125 | 0.088 | 0.074 | 0.0625 | 0.032 | 0.016 | 0.008 |
| 110.0 | 100.0 | 100.0 | 99.8 | 97.2 | 83.9 | 48.8 | 16.8 | 5.6 | 3.4 | 1.6 | | | |
| 120.0 | 100.0 | 99.4 | 98.8 | 98.3 | 97.3 | 95.1 | 87.6 | 70.6 | 62.6 | 58.2 | | | |
| 130.0 | 100.0 | 100.0 | 99.9 | 99.6 | 98.6 | 97.1 | 91.7 | 87.7 | 85.6 | 84.3 | | | |
| 135.5 | 100.0 | 100.0 | 100.0 | 100.0 | 99.8 | 78.0 | 37.8 | 30.2 | 28.2 | 27.6 | 4.3 | 3.0 | 2.5 |
| 137.5 | 100.0 | 99.8 | 99.8 | 99.8 | 99.6 | 91.0 | 51.6 | 44.4 | 42.8 | 42.4 | 17.8 | 11.2 | 10.0 |
| 140.0 | 100.0 | 99.9 | 99.7 | 99.1 | 98.2 | 97.2 | 78.4 | 64.1 | 60.8 | 59.5 | | | |
| 140.9 | 100.0 | 99.7 | 99.4 | 97.9 | 97.8 | 80.0 | 62.0 | 56.2 | 54.0 | 53.6 | 28.2 | 23.2 | 19.6 |
| 148.1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 99.4 | 80.6 | 73.0 | 71.0 | 70.6 | 39.0 | 33.6 | 29.0 |
| 155.4 | 100.0 | 99.6 | 99.6 | 99.6 | 99.6 | 99.6 | 99.6 | 99.2 | 98.8 | 98.6 | 54.8 | 46.0 | 42.0 |

Table F23

Bed-Material Fractions and Selected Grain Sizes for the Lower Mississippi River Based on Samples Collected by the U. S. Army Engineer Districts, Vicksburg and New Orleans

| Station or Reach | Mile | Period of Record | Number of Samples | Fraction (%)* | | | | | Selected Grain Sizes (mm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Gravel | Coarse Sand | Medium Sand | Fine Sand | Silt | $D_{84}$ | $D_{50}$ | $D_{16}$ |
| Arkansas City, Ark. | 550.4 - 581.0 | 1966-1974 | 1,729 | 3 | 2 | 25 | 68 | 2 | 0.55 | 0.34 | 0.23 |
| Vicksburg, Miss. | 422.8 - 451.8 | 1966-1974 | 1,308 | 5 | 3 | 42 | 48 | 2 | 0.75 | 0.44 | 0.27 |
| Natchez, Miss. | 355.2 - 381.4 | 1966-1974 | 1,219 | 2 | 1 | 32 | 63 | 1 | 0.55 | 0.36 | 0.22 |
| Tarbert Landing, Miss. | 306.3 | 1971-1977 | 283 | 2 | 1 | 20 | 76 | 1 | 0.48 | 0.28 | 0.17 |
| Mile 200 - Mile 300 | 208.4 - 295.0 | 1975 | 21 | | | 6 | 86 | 8 | 0.33 | 0.18 | 0.11 |
| Mile 100 - Mile 200 | 101.5 - 197.0 | 1975 | 55 | | 1 | 1 | 61 | 37 | 0.21 | 0.10 | 0.01 |
| Mile 0 to Mile 100 | 0.0 - 99.1 | 1975 | 86 | | | 1 | 32 | 67 | 0.13 | 0.05 | <0.004 |

* Fractions based on Unified Soil Classification System.

Table F24

Comparison of 1932/1934 and Post-1965 Bed-Material Data for the Lower Mississippi River from Arkansas City to Head of Passes

| Station or Reach | Fraction (%)* | | | | | | Selected Grain Size (mm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gravel | | Total Sand | | Silt | | $D_{84}$ | | $D_{50}$ | | $D_{16}$ | |
| | 1932/34 | Post 1965 | 1932/34 | Post 1965 | 1932/34 | Post 1965 | 1932/34 | Post 1965 | 1932/34 | Post 1965 | 1932/34 | Post 1965 |
| Arkansas City, Ark. | 7 | 3 | 88 | 95 | 5 | 2 | 0.90 | 0.55 | 0.40 | 0.34 | 0.16 | 0.23 |
| Vicksburg, Miss. | 8 | 5 | 89 | 93 | 3 | 2 | 0.80 | 0.75 | 0.36 | 0.44 | 0.14 | 0.27 |
| Natchez, Miss. | 4 | 2 | 96 | 96 | 0 | 2 | 0.60 | 0.55 | 0.34 | 0.36 | 0.15 | 0.22 |
| Talbert Landing, Miss. | 2 | 2 | 93 | 97 | 5 | 1 | 0.55 | 0.48 | 0.30 | 0.28 | 0.13 | 0.17 |
| Donaldsonville, La.**/ Mile 100-mile 200 | | | 97 | 63 | 3 | 37 | 0.40 | 0.21 | 0.21 | 0.10 | 0.12 | 0.01 |
| Head of Passes† Mile 0-mile 100 | | | 92 | 33 | 8 | 67 | 0.25 | 0.13 | 0.17 | 0.05 | 0.11 | <0.004 |

* Fractions based on Unified Soil Classification System.

** Donaldsonville data are for 1932/1934; mile 100-mile 200 data are for 1975.

† 1932/34 data for location 50 miles upstream of the Head of Passes in order to compare with the reach from mile 0 to mile 100.

Table F25

Bed-Material Fractions and Selected Grain Sizes for the Lower Red River, Old River Outflow Channel, and Atchafalaya River

| Stream | Station or Reach | Mile | Period of Record | Number of Samples | Fraction (%)* | | | | | Selected Grain Sizes (mm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Gravel | Coarse Sand | Medium Sand | Fine Sand | Silt | $D_{84}$ | $D_{50}$ | $D_{16}$ |
| Red River | Above Old River Outflow Channel, La. | 13.1** | 1971-1976 | 80 | | | 9 | 55 | 36 | 0.36 | 0.15 | 0.05 |
| Old River Outflow Channel | Near Knox Landing, La. | 5.5† | 1971-1976 | 106 | 2 | 1 | 30 | 67 | | 0.66 | 0.37 | 0.28 |
| Atchafalaya | Simmesport, La. | 8.2†† | 1971-1976 | 151 | | 1 | 29 | 70 | | 0.58 | 0.37 | 0.26 |
| Atchafalaya | Mile 0-Mile 50 | 0.0-50.0†† | 1975-1976 | 40 | | 1 | 17 | 73 | 9 | 0.46 | 0.27 | 0.15 |
| Atchafalaya | Mile 50-Mile 100 | 60.0-100.0†† | 1975-1976 | 48 | | | 5 | 74 | 21 | 0.28 | 0.20 | 0.05 |
| Atchafalaya | Mile 100-Mile 140 | 105.0-140.0†† | 1975-1977 | 35 | | | 2 | 51 | 47 | 0.19 | 0.08 | 0.04 |
| Atchafalaya | Morgan City, La. | 117.8†† | 1972-1977 | 23 | | | 1 | 31 | 68 | 0.091 | 0.045 | 0.004 |
| Wax Lake Outlet | Calumet, La. | 119.6†† | 1972-1977 | 18 | | | 1 | 9 | 90 | 0.057 | 0.015 | <0.001 |

* Fractions based on Unified Soil Classification System.
** Red River mile.
† Old River Outflow Channel mile. (Mile 0.0 is at the confluence of the Outflow Channel with the Mississippi River.)
†† Atchafalaya River mile. (Mile 0.0 is at the confluence of the Red and Lower Old Rivers.)

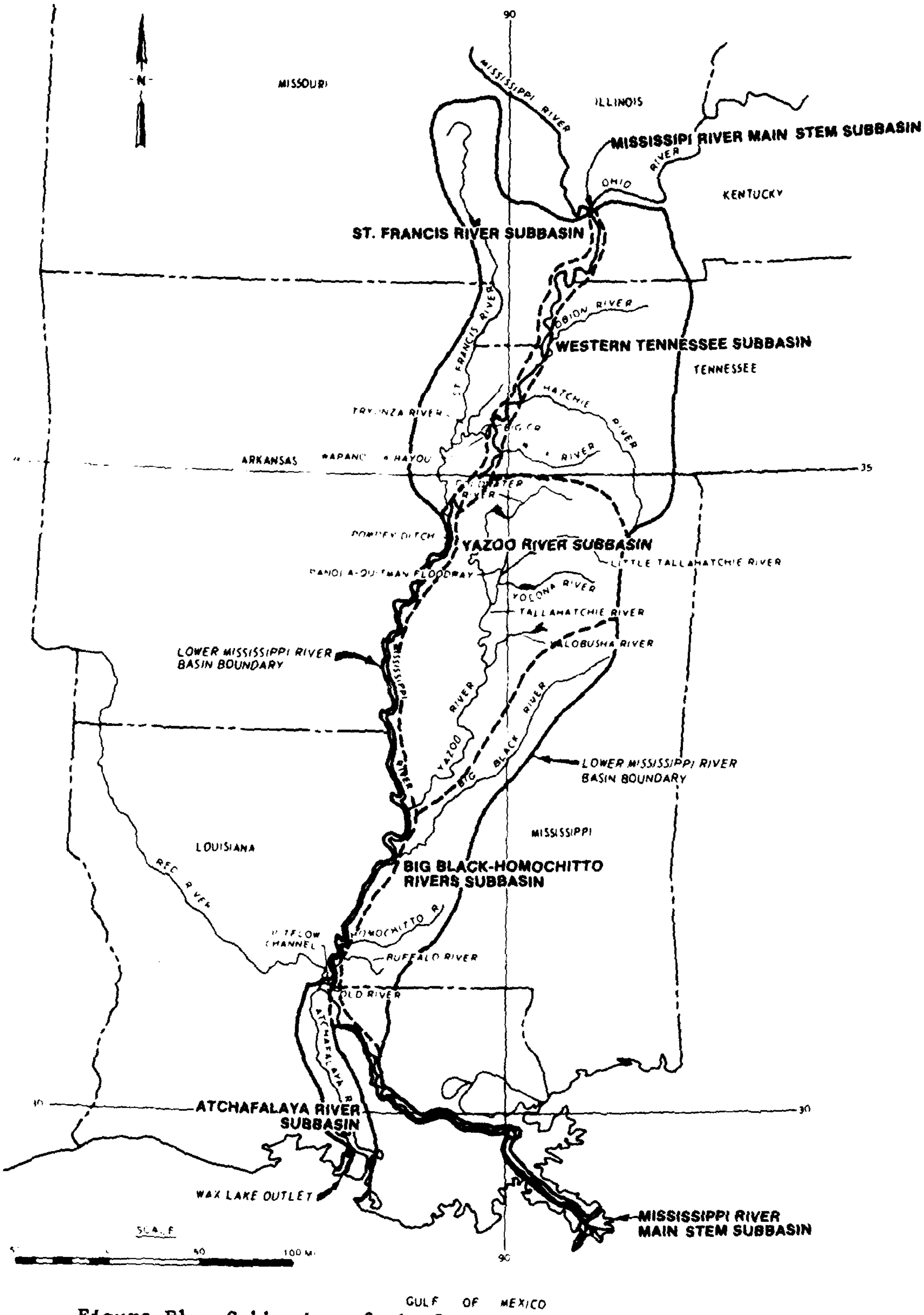


Figure F1. Subbasins of the Lower Mississippi River Basin

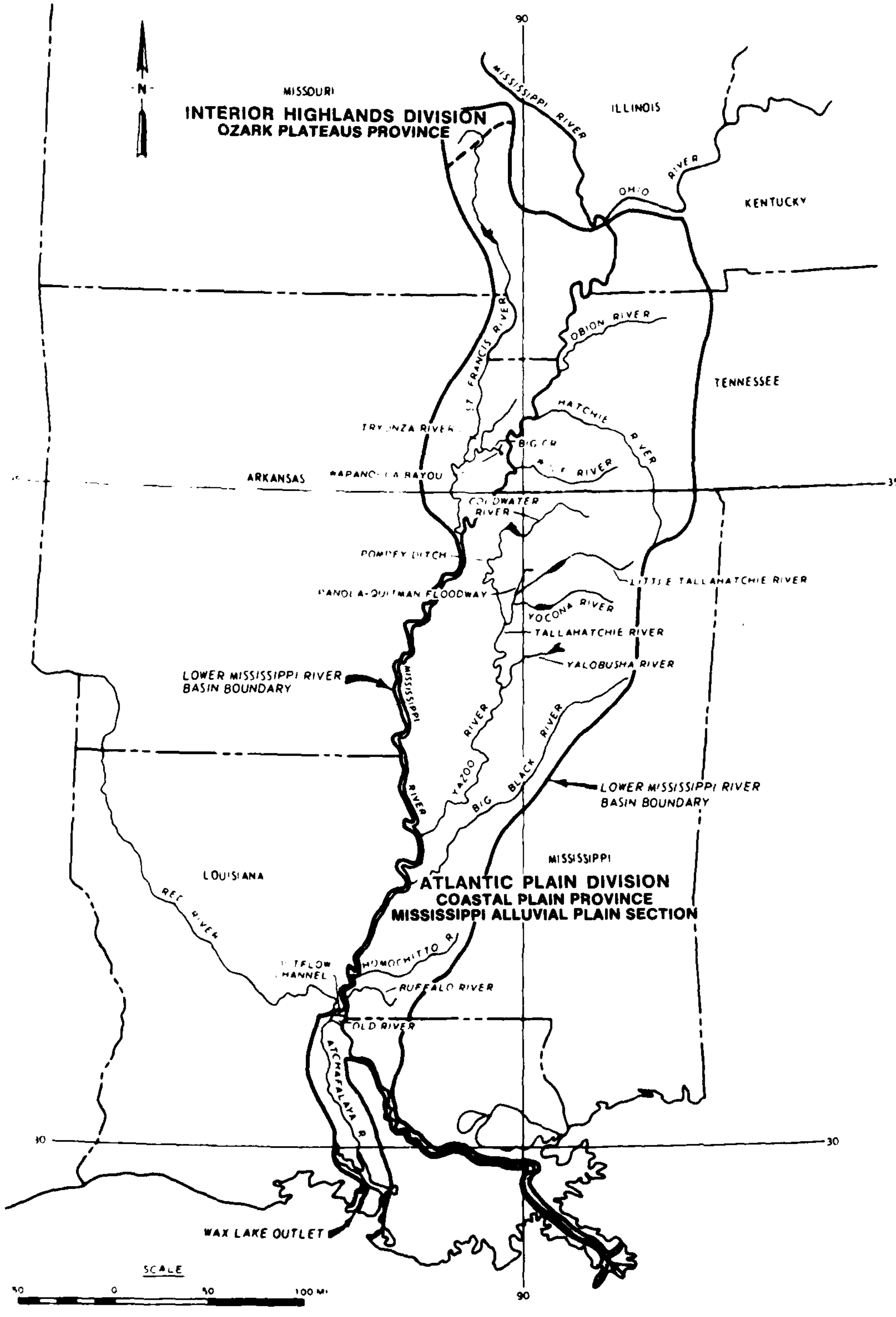


Figure F2. Physiographic map of the Lower Mississippi River Basin (Adapted from Reference 1)

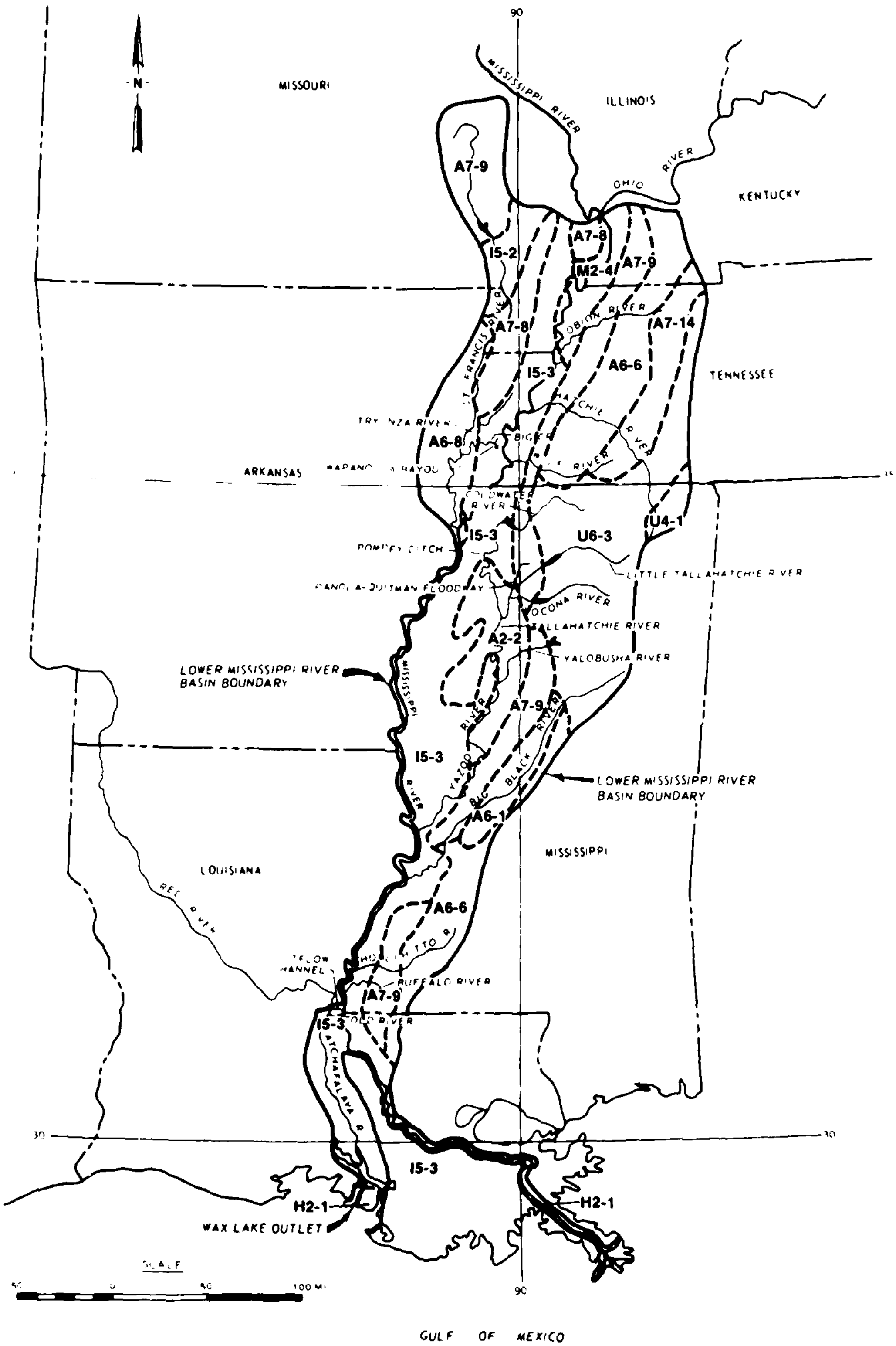


Figure F3. Soils map of the Lower Mississippi River Basin (Legend for the soil classification in Table 1 of the main text)

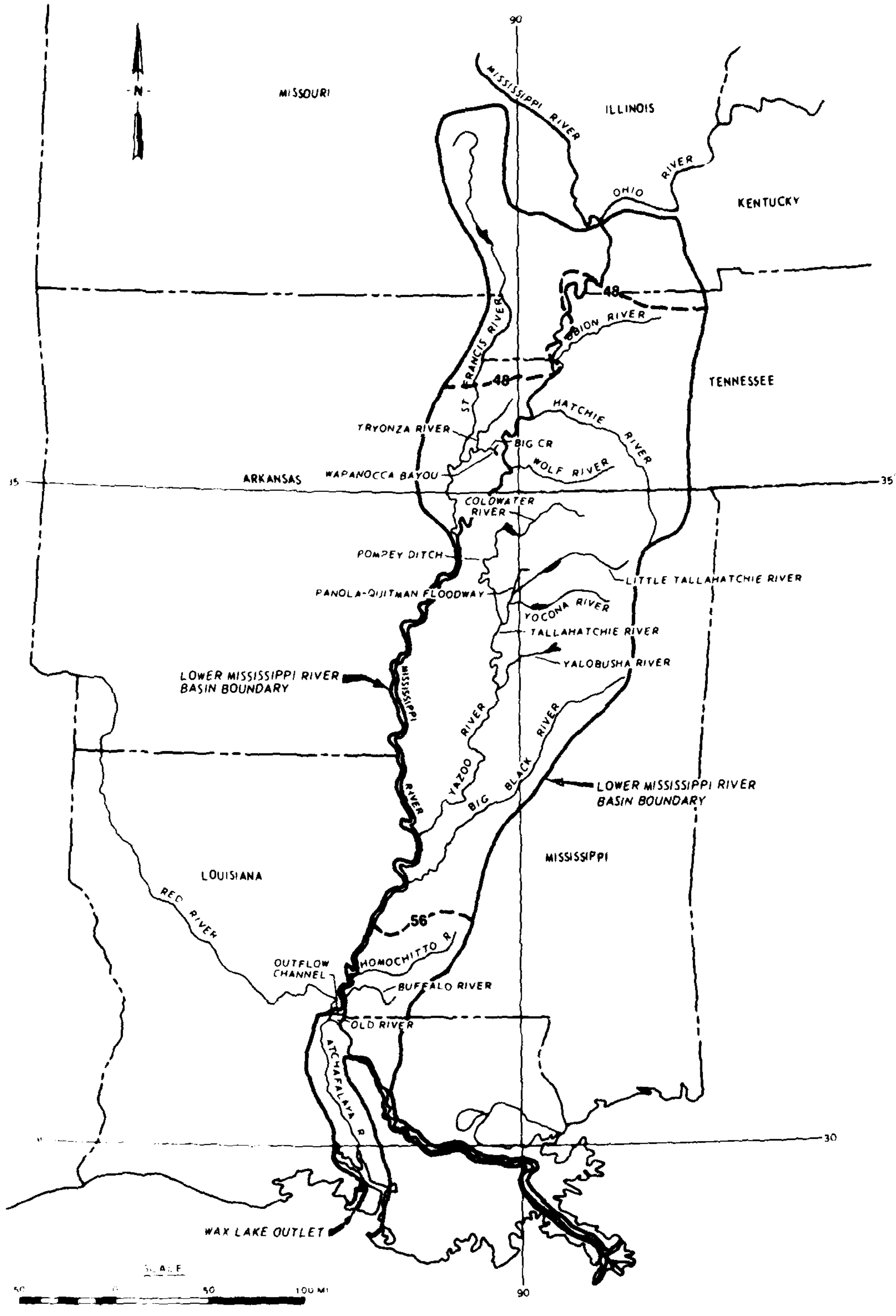


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Figure F4. Mean annual total precipitation (in.) over the Lower Mississippi River Basin (Adapted from Reference 1)

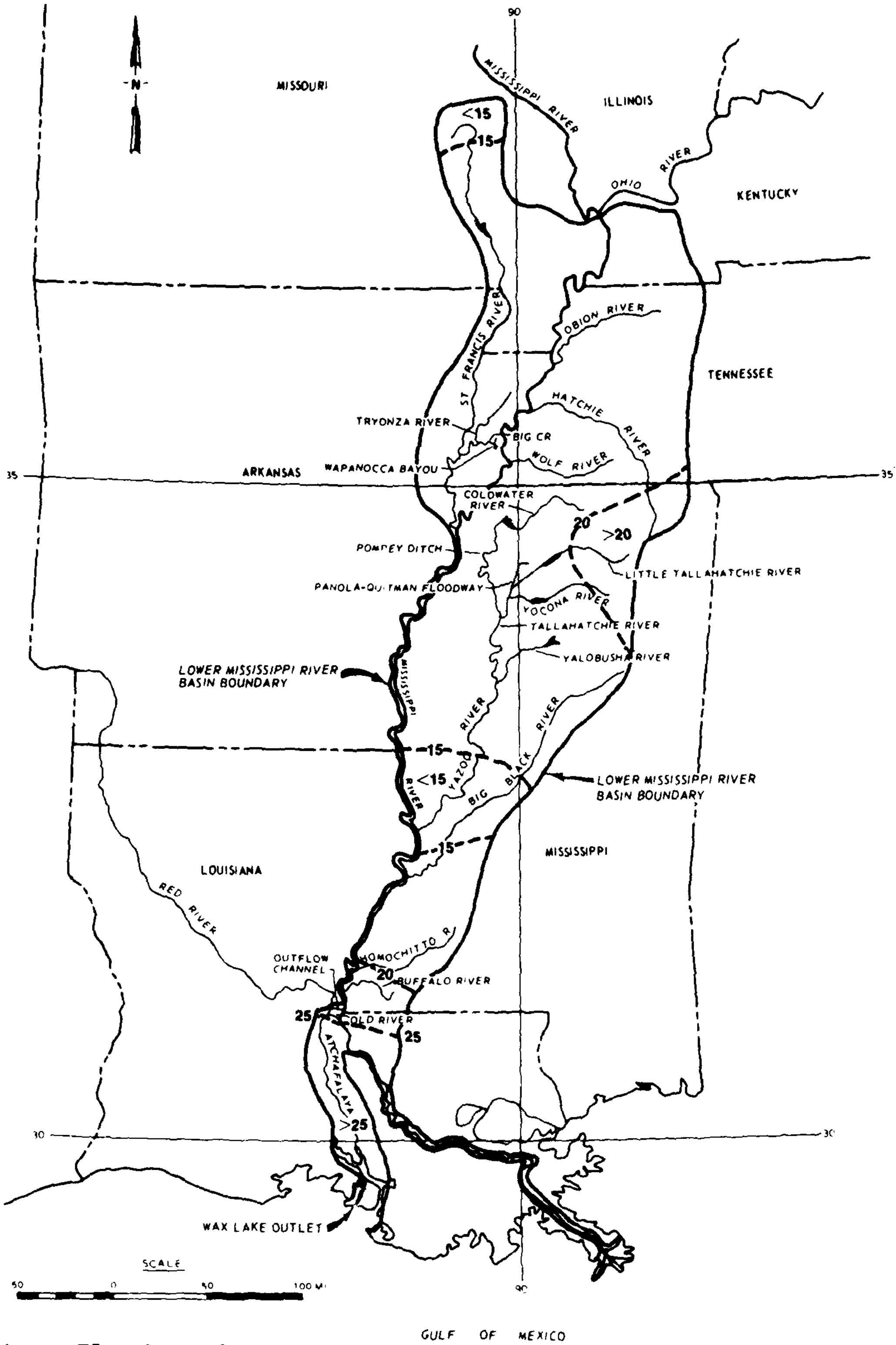


Figure F5. Generalized estimates of mean annual runoff (in.) in Lower Mississippi River Basin (Adapted from Reference 1)

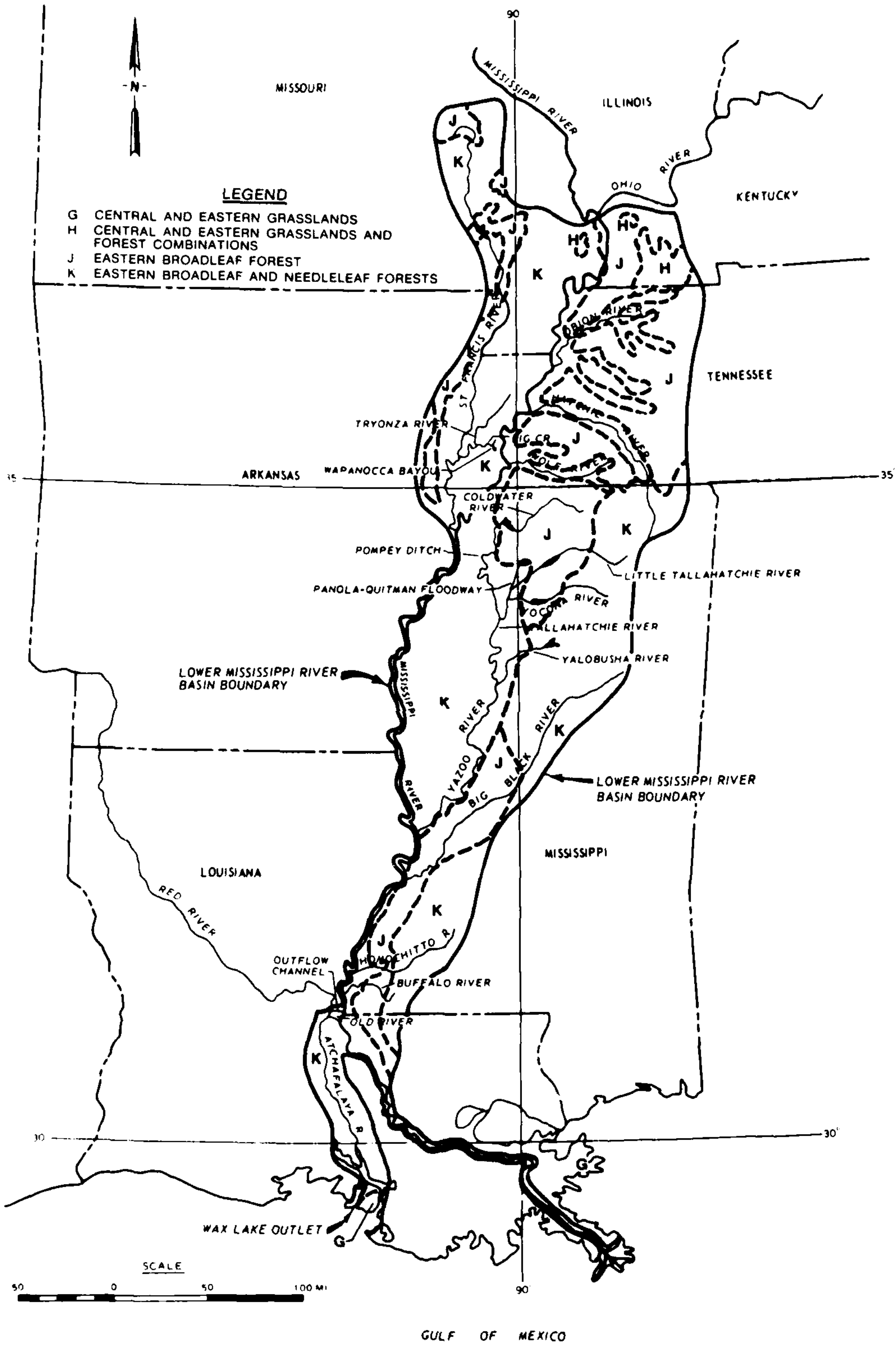


Figure F6. Potential natural vegetation of the Lower Mississippi River Basin (Adapted from Reference 6)

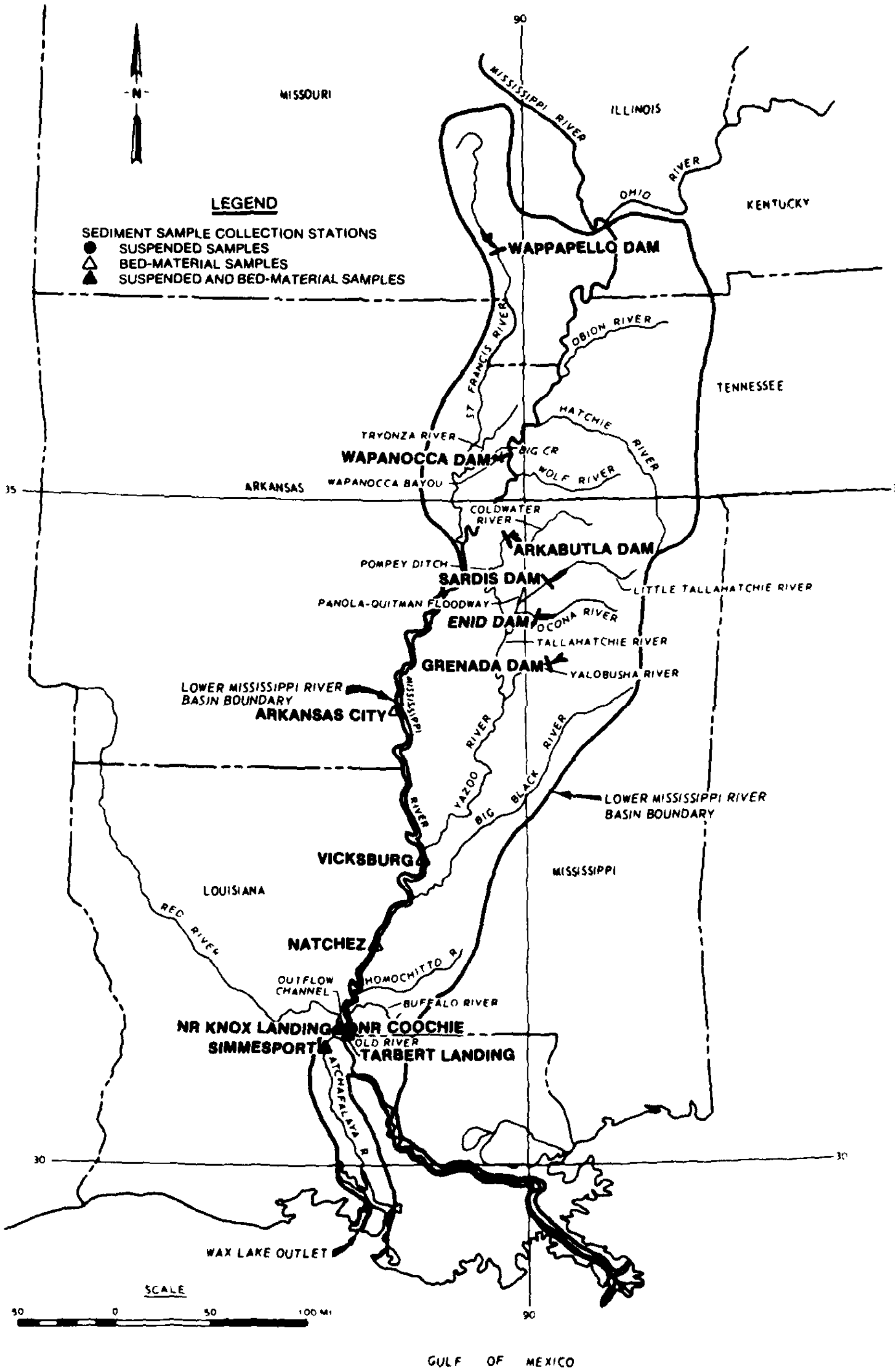


Figure F7. Locations of dams and sediment sample collection stations in the Lower Mississippi River Basin

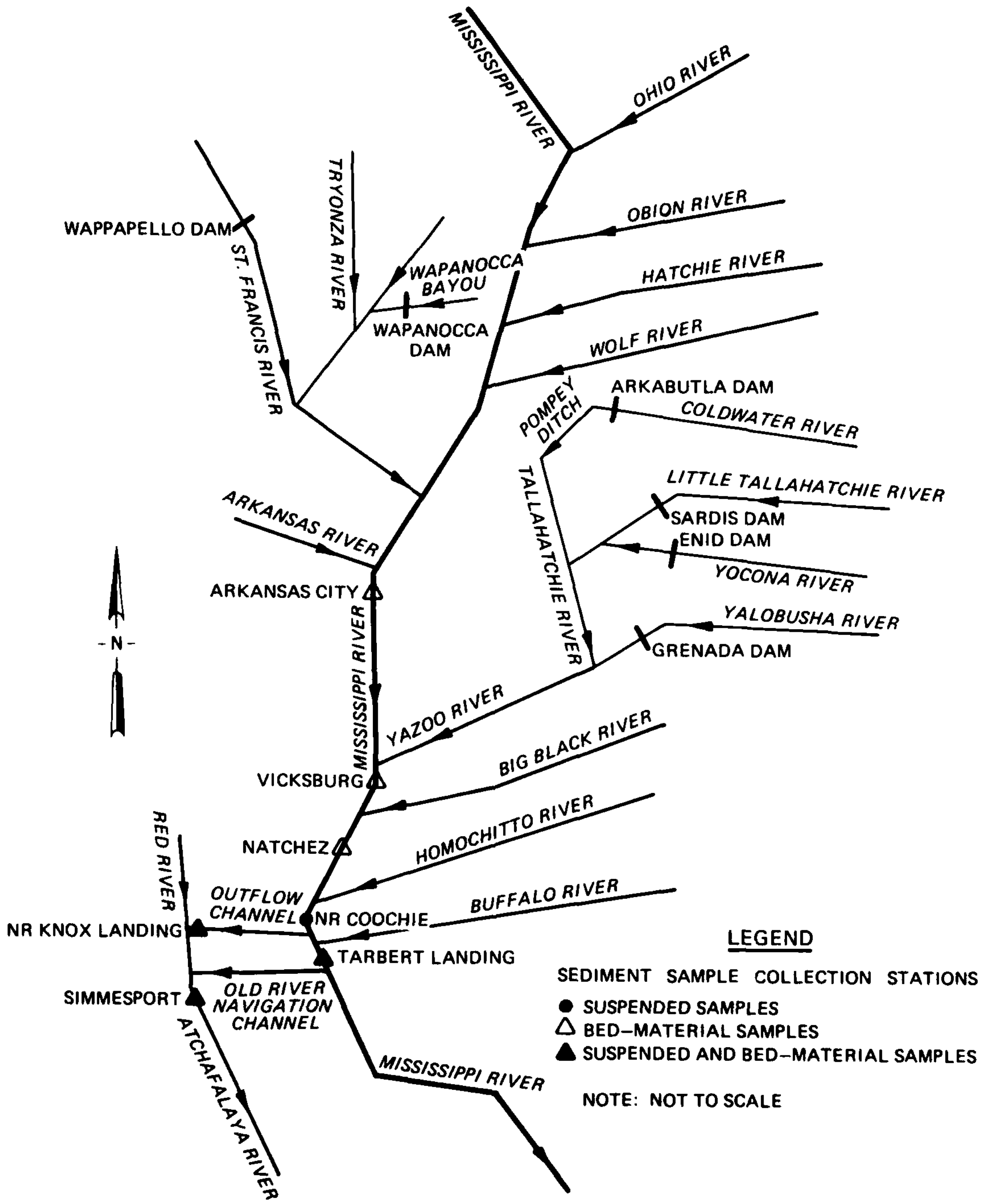


Figure F8. Locations of dams and sediment collection stations in the Lower Mississippi River Basin shown on linear streamflow diagram

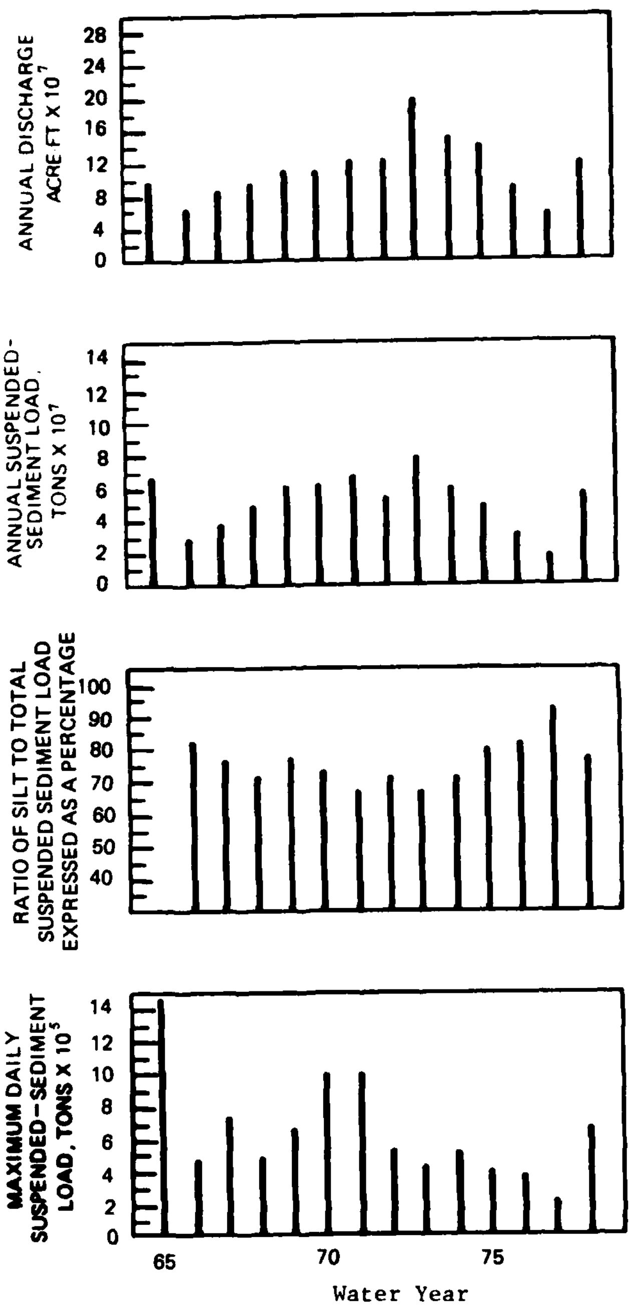


Figure F9. Annual discharge and suspended-sediment load, ratio of silt to total suspended-sediment load, and maximum daily suspended-sediment load for the station on Old River Outflow Channel near Knox Landing, La. (Note: Figures F9-F12 are presented by subbasin following the listing in Table F12.)

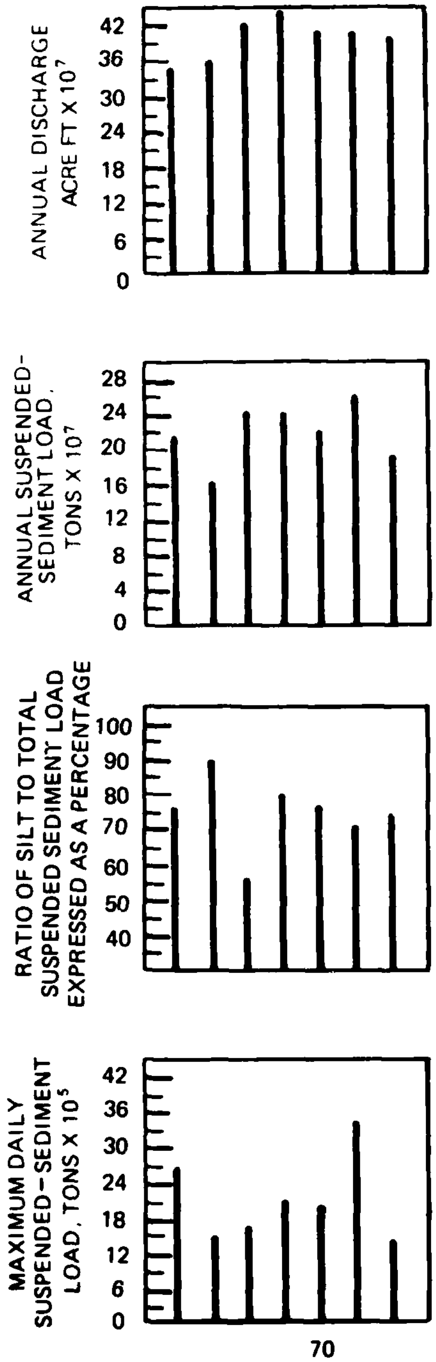


Figure F10. Annual discharge and suspended-sediment load, ratio of silt to total suspended-sediment load, and maximum daily suspended-sediment load for the station on Mississippi River near Coochie, La.

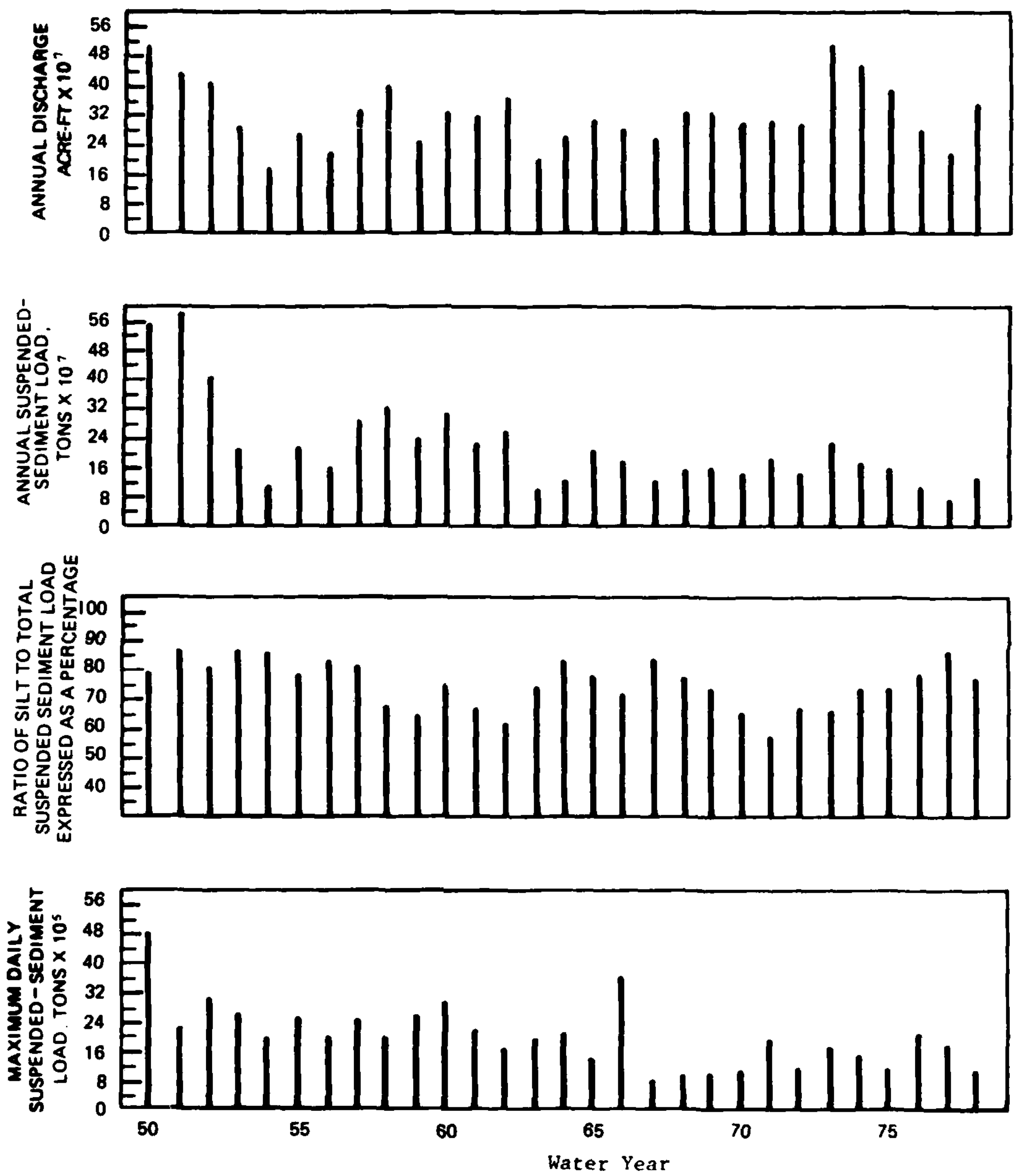


Figure F11. Annual discharge and suspended-sediment load, ratio of silt to total suspended-sediment load, and maximum daily suspended-sediment load for the station on Mississippi River at Tarbert Landing, Miss.

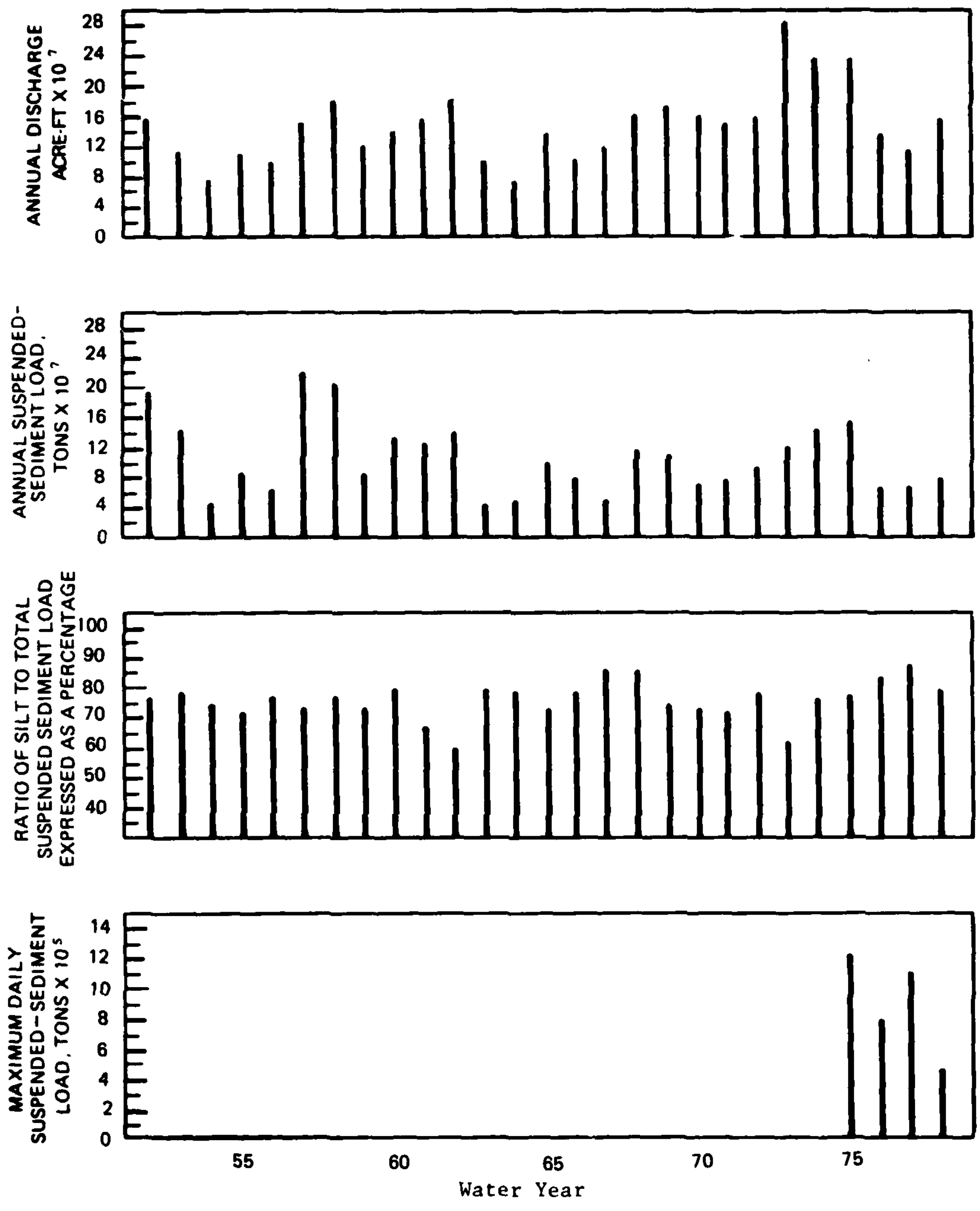


Figure F12. Annual discharge and suspended-sediment load, ratio of silt to total suspended-sediment load, and maximum daily suspended-sediment load for the station on Atchafalaya River at Simmesport, La.

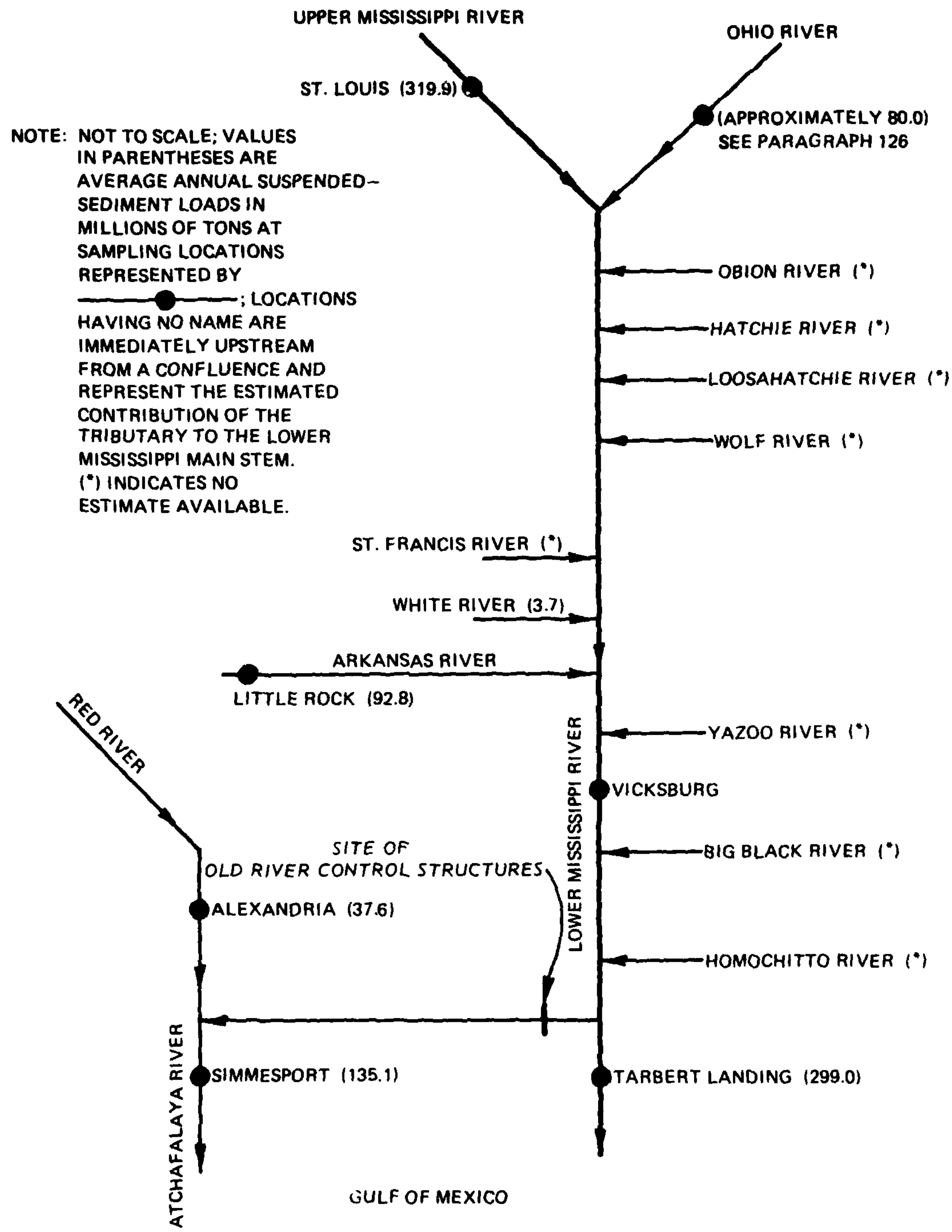


Figure F13. Lower Mississippi River suspended-sediment flow regime prior to the Old River Control Structures becoming operational (1963) and closure of several major multiple purpose dams in the Missouri River Basin (1953-1967) and in the Arkansas River Basin (1963-1970)

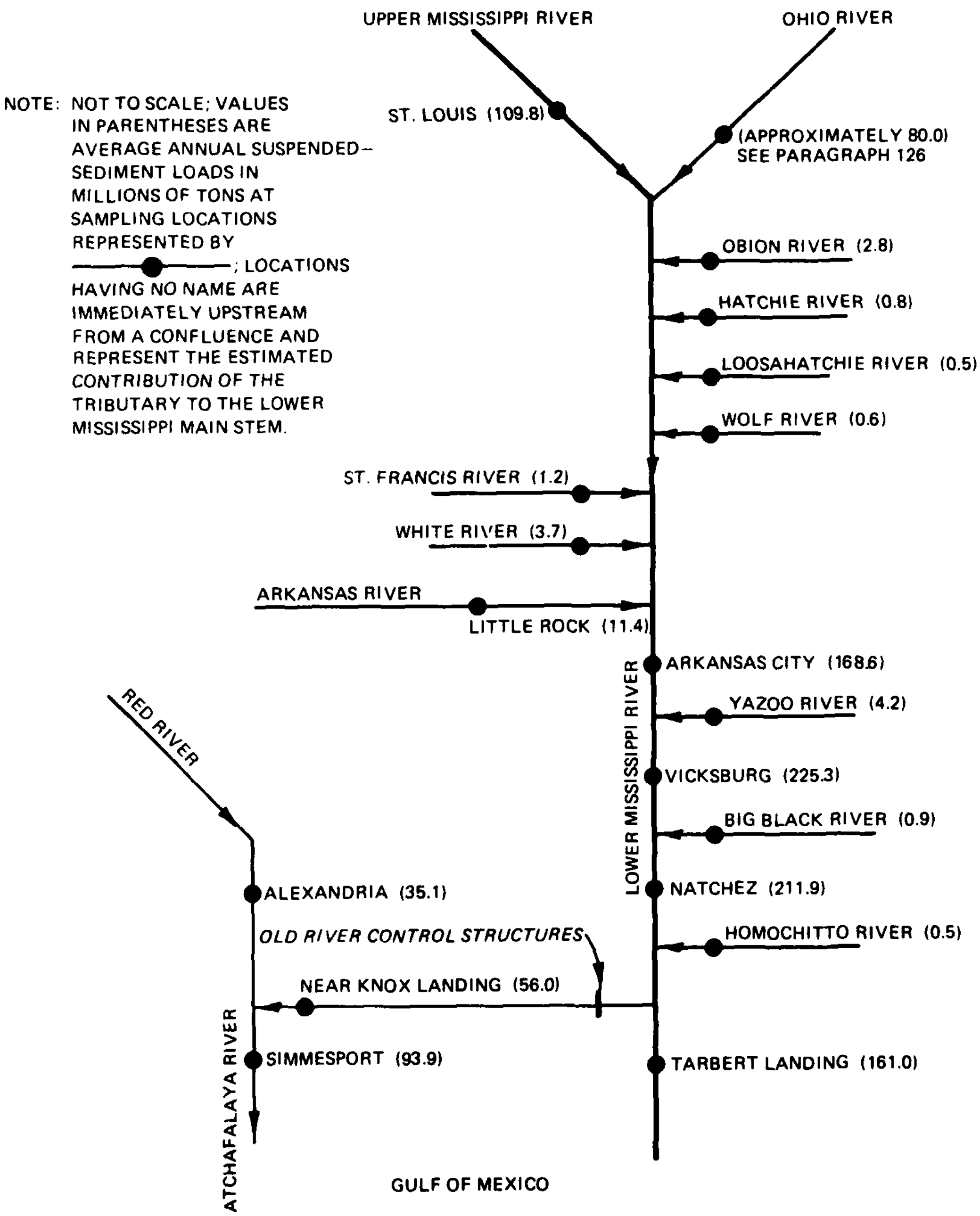


Figure 14. Current (1970 to 1978) Lower Mississippi River suspended-sediment flow regime

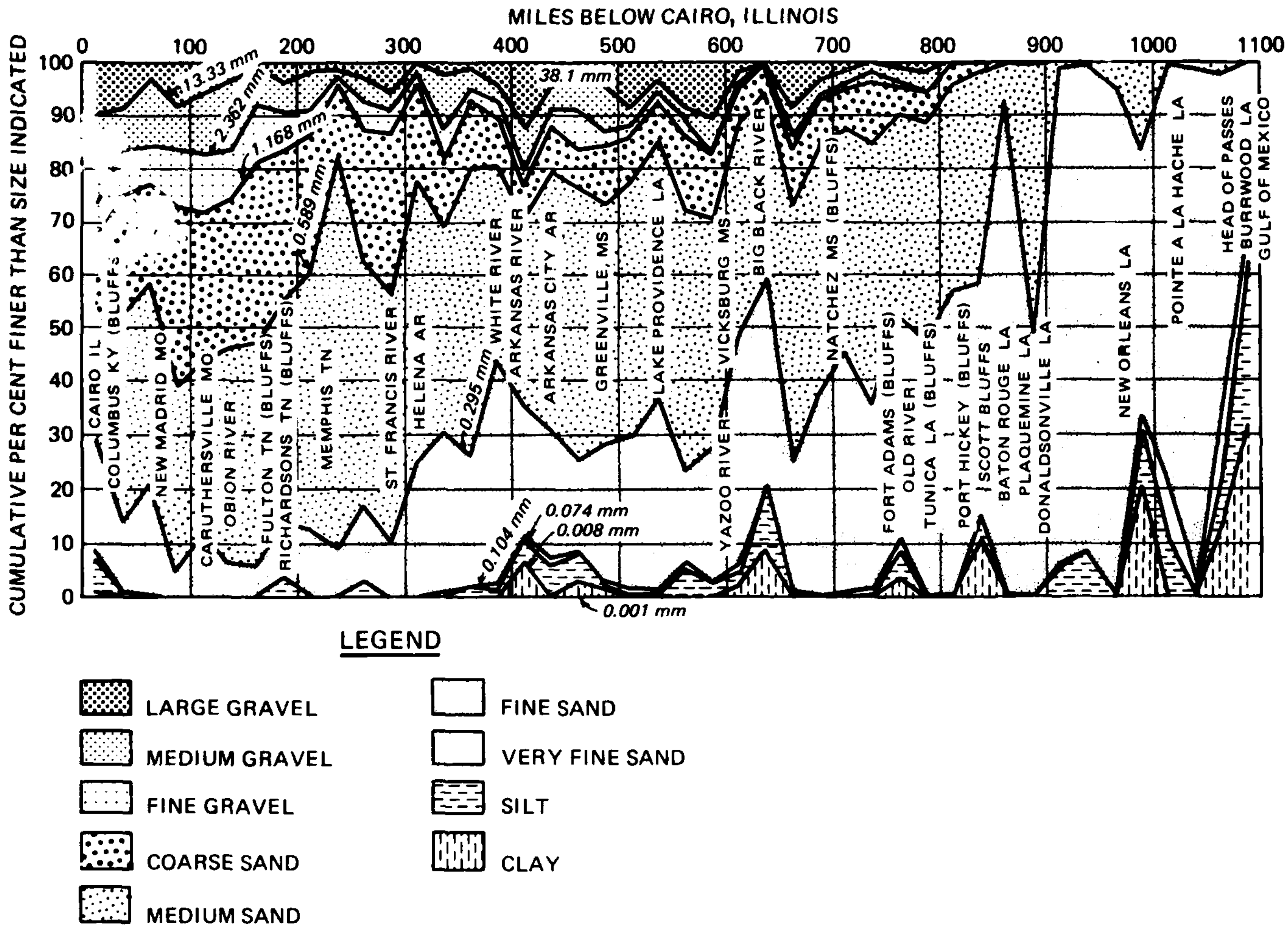


Figure F15. Bed-material gradation of the Lower Mississippi River based on 615 samples collected by the Mississippi River Commission during August-September 1932 and May 1934 from mile 0 to mile 1,091 below Cairo, Ill. (Source, Reference 55)

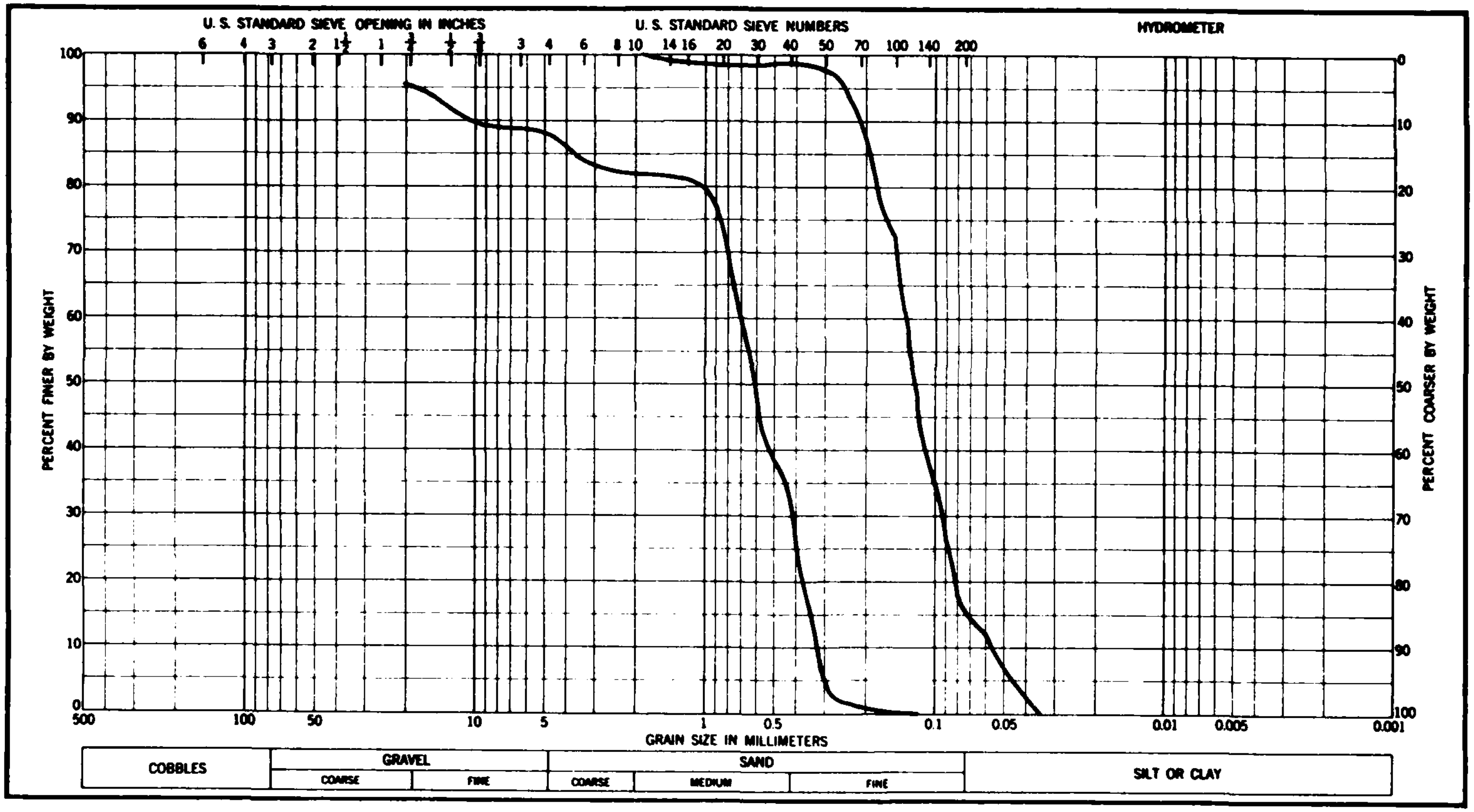


Figure F16. Bed-material gradation envelope for the Atchafalaya River at Simmesport, La., 1971-1976

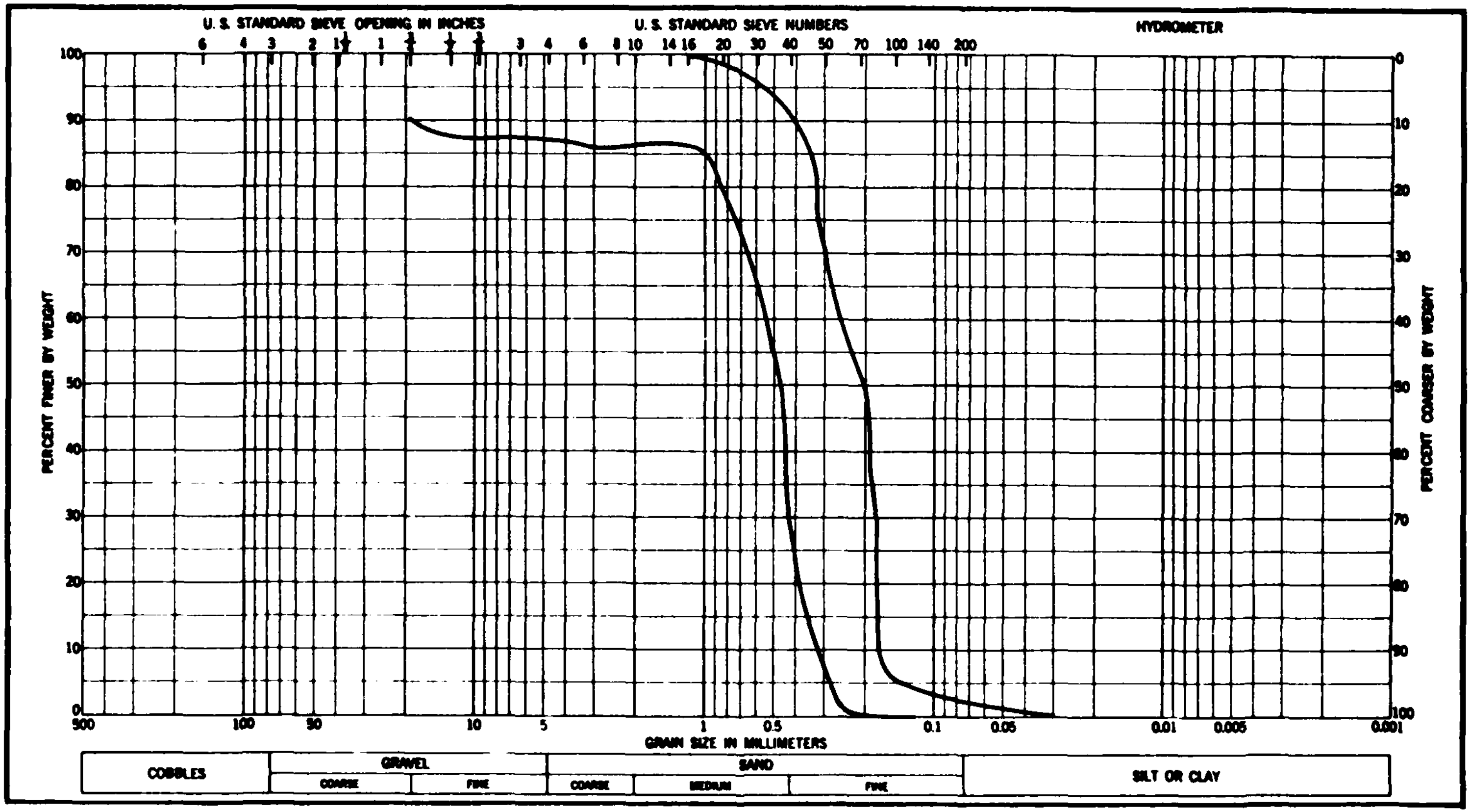


Figure F17. Bed-material gradation envelope for Old River Outflow Channel near Knox Landing, La., 1971-1976

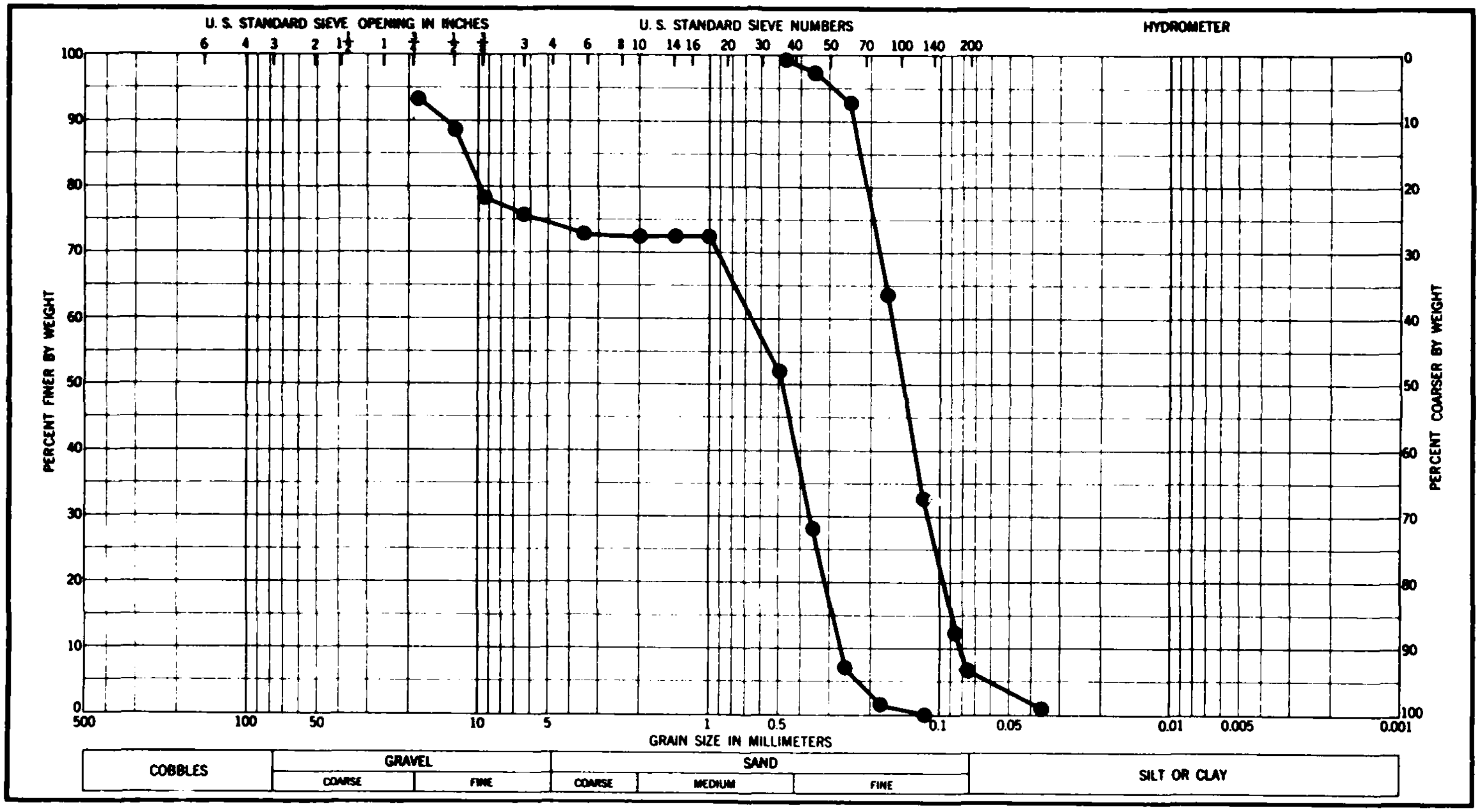


Figure F18. Bed-material gradation envelope for the Mississippi River at Tarbert Landing, Miss., 1971-1977

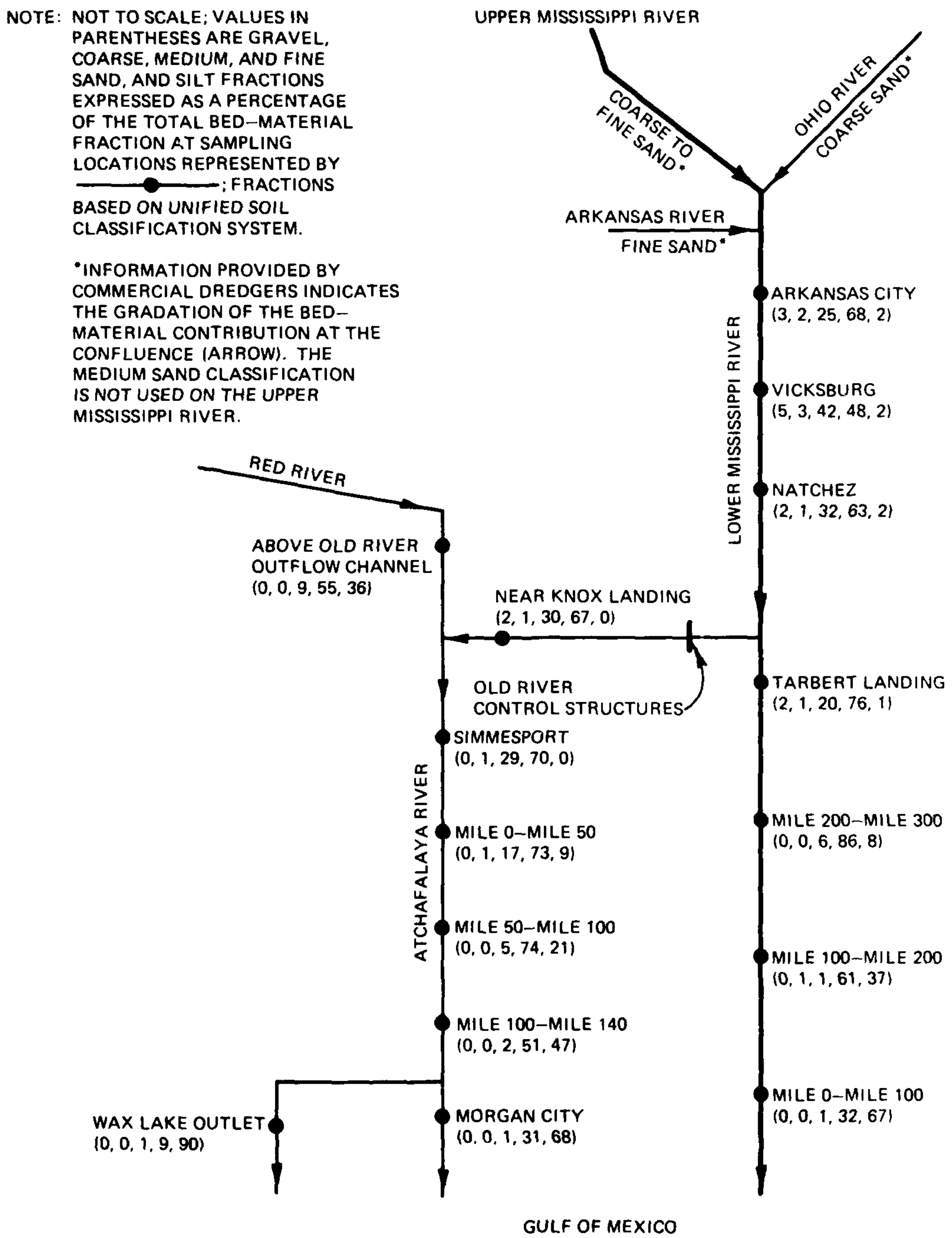


Figure F19. Current (using available data, 1966-1979) bed-material regime of the Lower Mississippi River

## APPENDIX G: INDEX

Letters in parentheses following suspended-sediment sample and bed-material collection station listings indicate the type of data provided in this report: (d) annual water discharge, (s) annual suspended-sediment load, (m) maximum daily suspended-sediment load, and (b) bed-material gradation.

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FILM